The technique provided here is a useful and realistic approach for the examination of volatiles in real magmas that evolve compositionally with time.

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V42C MC: Hall D Thursday 1330h

Volcanology: Monitoring and Risk

Presiding: **R Scandone,** University of Rome III

V42C-1024 1330h POSTER

The Evaluation of Volcanic Risk of Campi Flegrei (Italy)

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The volcanological history of Campi Flegrei suggests that the emplacement of pyroclastic flow and surge characterizes the most frequent eruptions occurred from different vents scattered over a 150 km2 wide caldera. The evaluation of volcanic risk in volcanic fields is complex because of the lack of a central vent. To approach this problem, we subdivided the entire area of Campi Flegrei into a regular grid and evaluated the relative spatial probability of opening of vents basing on geological, geophysical and geochemical data. We evaluated the volcanic risk caused by pyroclastic flows basing on the formula proposed by UNESCO (1972) R= H x V x Va, where H is the hazard, V is the vulnerability and Va is the value of the elements at risk. The product H x V was obtained by performing simulations of type eruptions centered in each cell of the grid. The simulation is based on the energy cone scheme proposed by Sheridan and Malin (1983), hypothesizing a column collapse height of 100 m for eruptions of VEI=3 and 300 m for eruptions of VEI=4 with a slope angle of 6°. Each simulation has been given the relative probability value associated with the corresponding cell. The vulnerability linearly decreases with the distance from the vent. We made use of the GIS software ArcView 3.2 to evaluate the intersection between the energy cone and the topography. The superposition of the areas invaded by pyroclastic flows (124 simulations for VEI=3 and 37 for VEI=4) was used to obtain the relative vulnerability map of the area. The relative volcanic risk map is obtained by superimposing the urbanization maps.

V42C-1025 1330h POSTER

Summary of the historical eruptive activity of volcn de Colima, Mexico 1519-2000

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Volcn de Colima (103^{circ}37'W, 19^{circ}30'45"N) has had significant eruptive activity over the last 5 centuries, leading to its designation as the most active volcano in Mexico. This activity has manifested itself through a variety of eruptive processes, culminating in explosive events rated VEI 4. Much of our knowledge of the earlier volcanic events is from non-scientific writings and as such is only an interpretation of sometimes ambiguous information. The most recent eruptions of the 19th and 20th centuries are, however, well documented scientifically allowing for more detailed understanding of these events. Numerous cities and towns, numbering up to 390,000 persons, are at risk from hazards posed by a Plinian or Subplinian eruption. Pyroclastic flows accompanying the 1818 and 1913 eruptions reached distances of 15 km, strong ash fell over 30 km distance, and lesser ash falls reached many hundreds of kilometers. It is to be remembered that at present there are a number of towns within Colima and Jalisco States that could be seriously affected by such an eruption: pyroclastic flows, ash falls, and lahars being the major threats. Although the historical record does not permit forecasting the start of such activity, it gives abundant evidence that this style of volcanism will no doubt occur in Colima's future.

V42C-1026 1330h POSTER

Stability Evaluation Of Previous Volcanic Edifice Collapse At Pico De Orizaba Volcano, Mexico, Using Geotechnical Techniques

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Pico de Orizaba volcano has collapsed twice during its geologic evolution (Carrasco-Nuñez, 1997). The initial stage of evolution for this volcano is known as the Torrecillas cone that collapsed 0.21 Ma b.p., and the related deposits formed the Jamapa avalanche which traveled eastward 75 km. A second, superimposed constructional stage is the Espoln de Oro cone that also ended with a collapse 20 000 years b.p., forming the Tetelzingo avalanche-lahar that traveled 85 km. Samples from the remains of old summit cores and their corresponding collapse deposits were collected and tested in order to obtain strength parameters of altered rock from old volcanic edifices. Hydrothermal alteration and variations of strength of the two avalanche deposits were correlated with the strength values and alterations from the in situ corresponding sources. Strength values: Hoek and Brown's parameters, Uniaxial Compressive Strength (50-300 kPa), cohesion (480-2000 kPa), angle of friction (6°- 35°); and degree of alteration give insights of rock mass quality and maximum intact rock strengths of the edifice rock mass. These values provide the upper limits for numerical model input parameter values for evaluation of flank stability. Rock strength from numerical model of previous failures can be compared with those obtained for the rock mass and intact rock of the actual edifice. This would permit the assessment of future avalanche hazards.

URL: http://www.scs.unr.edu/~aline/current.html

V42C-1027 1330h POSTER

Development of the cosmic-ray muon detection system for probing internal-structure of a volcano

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Very high energy cosmic-ray muons penetrating through a mountain enable us to probe internal-structure of volacanoes by using the cosmic-ray muon energy spectrum and the range-energy relation of muons. An improved cosmic-ray muon detection system comprising two segmented detectors with multiplicity cut of the soft components of cosmic ray was developed. The result of the test measurement for the volcano Mt. Asama will be presented.

URL: http://nerv.riken.go.jp

V42C-1028 1330h POSTER

Intracaldera Lake Shorelines in the Taupo Volcanic Zone, New Zealand: Long-Term Versus Short-Term Deformation Trends

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Taupo Volcanic Zone is a region of active arc volcanism, deformation, and seismicity developed in association with rifting behind the Hikurangi subduction zone at the south end of the Tonga-Kermadec Trench. At Taupo volcanic center, a major ∼26.5 ka caldera system (now occupied by a large lake) cuts across the Taupo Fault Belt, a zone of late Quaternary extension and normal faulting. Short-term (<20 years) vertical deformation rates from geodetic and lake-levelling techniques reveal complex and episodic deformation trends, linked in part to local seismicity, overprinting a broader regional pattern. Medium-term deformation trends, defined relative to a paleolevel formed by a highstand shoreline developed within ∼15 years of the 1.8 ka Taupo eruption are broadly similar to these historic patterns. However, warping and offsetting of a highstand shoreline developed in the immediate aftermath of the 26.5 ka Oruanui eruption indicates rather different long-term deformation trends. Relative offsets on the 26.5 ka shoreline are only double those of the 1.8 ka shoreline, despite it being 15 times older, except where subsidence has been concentrated on a single, highly active fault. The 26.5 ka shoreline reaches its highest elevation in the middle of an inferred graben in the Taupo Fault Belt: extrapolation of short-term deformation rates at this site would place it below modern lake level. The inference is that the Taupo Fault Belt immediately north of Lake Taupo is largely isostatically compensated, with short-term patterns (years to centuries) of episodic uplift and subsidence cancelling out over longer time periods (tens of thousands of years). Long-term subsidence is instead apparently focussed to the east, in the actively deforming, little-faulted Taupo-Reporoa Basin, which hosts a lacustrine succession stretching back 300 ka. Usage of short-term patterns to indicate long-term deformation trends, or to demonstrate caldera unrest at Taupo volcanic center is inappropriate, as such patterns may simply represent elastic responses to continued horizontal extension across the Taupo Volcanic Zone, made manifest by the presence of Lake Taupo as a horizontal datum.

V42C-1029 1330h POSTER

Precise Repicking and Relative Relocation of Volcanic Earthquakes at Soufriere Hills Volcano Reveals Distinct, Stationary Sourcs for Early Earthquake Swarms

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We have performed automatic, waveform correlation-based phase repicking and a multi-tiered method of clustering to isolate distinct families of repeating seismic events at Soufriere Hills Volcano, Montserrat, for July, 1995 - February, 1996. 75 large clusters of simliar events have been identified. These clusters correspond to times of significant swarming activity at the volcano. Families segregated by waveform differences tend also to be separated from one another in time, and each spans at most a few days.

Earlier families are volcano-tectonic in nature and represent brittle failure in association with phreatic activity near the summit crater. Hypocenters could not be estimated for these events due to poor signal/noise ratio at most stations; however, repeatability of waveforms at the summit station suggests a consistent source region within each of these clusters. Rapid attenuation with distance indicates extremely shallow depths, and we interpret these events as occurring very near the volcano edifice.

Later clusters can be located with traditional earthquake location methods. These events coincide temporally with observed dome extrusion. They are characterized by high-frequency onsets exhibiting mixed first motions, followed by long period codas of tens of seconds' duration. These volcanic hybrid event swarms occur within discrete source regions of at most a few hundred meters' diameter. Some clusters are spatially

separated from others by as much as 0.5 to 1.5 km. Although absolute epicenters and depths are uncertain, relative cluster centroid separations are robust. Reduced attenuation confirms relatively greater depths for these later clusters. Temporal evolution of the swarms shows a gradual decrease in inter-event time as each swarm develops.

V42C-1030 1330h POSTER

Recent Eruptive History of La Malinche Volcano, Mexico: Towards the Construction of a Hazards Map

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La Malinche (4,461 m asl) is a potentially active andesitic-dacitic stratovolcano situated 25 km to the NE of Puebla, Mexico (1.3 million inhabitants). The oldest rocks in the area are Cretaceous limestones that crop out to the S and SE of La Malinche. To the W and N Tertiary lacustrine sediments are covered by younger sedimentary and pyroclastic material. The northern lacustrine sediments are overlain by andesitic rocks that form a chain of lava domes along a general E-W trend. La Malinche's eruptive history has been predominantly explosive during the last 45,000 y. Episodes of dome growth at the summit culminate with the emplacement of pyroclastic flows from dome colapse, and associated lahars. Four important pumice fall events are registered in the stratigraphy: The two oldest are more than 39,000 y. B.P., the next was dated at 21,500 y. B.P. and the youngest has an age that ranges beetwen 12,000 and 9,000 y. B.P. All of these events also produced pyroclastic flows. The oldest pyroclastic flow deposits dated are >39,000 y. B.P., and the youngest are 9,000 and 7,500 years old. Two minor partial edifice colapse events were dated at 29,500 y. B.P. and less than 23,700 y. B.P. The most recent eruption from La Malinche produced an ash-fall layer and ash-flow deposits dated at 3,100 y. B.P. In the documented stratigraphy, block-and-ash flows and pumice-and-ash flows have had maximum runouts in the range of 7-15 km. The two debris avalanche events had maximum runouts of 14 and 17 km. Lahar deposits can be observed more than 20 km from the summit.

Because the area around La Malinche is densely populated, we are concerned with the lack of an adequate hazards map. In addition to stratigraphic results we plan to employ computer tools that will simulate runout distances and travel times of potential future flow events to produce a hazards map.

V42C-1031 1330h POSTER

Surface Deformation at the Soufriere Hills Volcano, Montserrat, B.W.I.: Short Term Analysis of Continuous GPS Data During Periods of High Activity

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Continuous Global Positioning System (CGPS) data have been collected at the Soufriere Hills volcano, Montserrat, and used to measure surface deformation during the current eruption (1995-2000). The data were reprocessed to determine whether absolute point positioning averaged over 24, 12, and 4 hour periods is sufficiently precise to record significant magmatic events as manifested by surface activity and seismicity. A rapid change in the position of the continuous sites was observed during the explosion of September 17-18, 1996. The CGPS site at Reid's Hill Estate (REID), located about 3 km southwest of the active growth area, moved north about 30 mm (±2 mm) and subsided 45-60 mm (±8 mm). This change was followed by a period of strain relaxation, when the site moved back to its original trend. The site at Hermitage Estate (HERM), located less than 1.5 km northeast of the dome, subsided about 40 mm (±15 mm), but no short term trends were found in the horizontal component. Reprocessing the data in shorter intervals (12 and 4 hours) confirmed the results. The detection limit of the GPS technique is likely between 12 and 4 hours for similar magnitude magmatic events at stratovolcanoes in the tropics. A major change in the GPS data was observed before the second phase of dome growth started (November 1999), serving as a significant precursor to this important event. Other measurements (i.e. dome growth parameters, extrusion and ascent rates) are not taken with enough temporal precision to correlate with the observed changes recorded by the CGPS.

V42C-1032 1330h POSTER

New Seismic Data From Okmok Volcano, Alaska, Using a Rapid Response Seismic Recording System

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In June and August, 2001 we deployed several portable seismometers on Okmok volcano, Umnak Island, Alaska. This marks the first seismic study of Okmok since 1946 and the first deployment of digital recording systems on the volcano. The first experiment involved two temporary (∼7 day) digital systems and two analog drum recorders, and the second deployment consisted of two digital systems. We also conducted an experiment inside the caldera to investigate activity associated with cone A, the vent for the most recent (1997) eruption of Okmok. For this we took 10-minute recordings at 18 sites and compared tremor amplitudes with distance from the vent.

Results from the caldera profiles indicate the presence of seismic tremor (f=2.3 Hz) at Okmok, with the strongest amplitudes recorded at sites between the caldera center and cone A. Unfortunately, data from a crossing profile line were compromised by high winds so we were unable to locate the tremor source, but evidence of tremor was found only within the caldera. The long-term systems detected >80 earthquakes, several of which were regional events. However, a seismometer deployed in the center of the Okmok caldera detected a sequence of small, low-frequency (1-5 Hz) events that may be related to hydrothermal activity in the caldera. During the two deployments we identified three excellent sites for eventual deployment of a permanent seismic network on Okmok.

The instruments used for the study were designed at the Alaska Volcano Observatory for use in rapid response situations. Signals from an L-4C (T=1 sec) geophone were amplified then digitized with a Pico Technology ADC-42 digitizer connected to a laptop PC. The computer clock was synchronized every minute by a GPS receiver connected via the serial port. The computer clock was then used to time stamp the data. Because each instrument used a different type of PC, power consumption varied, with systems running 2-6 days on two 12-V batteries. Most of the problems encountered during the experiment resulted from the PC itself or with battery connections. The entire system (without batteries) fits into a relatively small (45 x 15 x 30 cm) Pelican case and can be deployed by one person in about 10 minutes.

V42C-1033 1330h POSTER

The 1997 Eruption of Okmok Volcano, Alaska, a Synthesis of Remotely Sensed Data

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Okmok Volcano in the central Aleutian Islands erupted in February of 1997. The eruption produced a lava flow in the central caldera over 5.5 $x10^7$ m^3 in volume over 7.5 km^2. This caldera is the most active of the Aleutian Arc, and is now the focus of international multidisciplinary studies. A synthesis of remotely sensed data (AIRSAR, derived DEMs, Landsat MSS and TM data, AVHRR, ERS, JERS, Radarsat) has given a sequence of events for the virtually unobserved 1997 eruption. Elevation data from the AIRSAR sensor acquired in October 2000 over Okmok was used to create a 5m resolution DEM mosaic of Okmok. AVHRR night-time imagery has been analyzed between February 13 and April 11, 1997. Landsat imagery years before and after the eruption allow us to accurately determine the extent of the new flow. The flow began without precursory thermal anomalies on Feburary 13th. At this point, the flow was a large single lobe, flowing north, ranging in thickness from 4 to 20 m. The eruption rate of this flow in the early stages is estimated as 2.5 m^3/s. According to AVHRR Band 3 and 4 radiance data and ground observations (overflight on Feb. 28), the first lobe had reached its maximum extent by February 28, while a second, smaller lobe began effusion sometime between March 1st - 4th. This is based on a jump in the thermal and volumetric flux determined from satellite imagery, and the physical size of the thermal anomalies. This flow continued with an eruptive rate of about 5 m^3/s. The total AVHRR radiance reached a maximum on March 12, which may indicate the peak areal extent for both lobes. Total radiance values waned after March 26, indicating lava effusion had ended and a cooling crust had formed. The total volume determined by eruption rates over time (ca. 1 x 10^8 m^3) agree well with the volume of the flow estimated using radar, Landsat, and later ground observations. Remote sensing has become an integral part of the Alaska Volcano Observatory's monitoring and hazard mitigation efforts. Studies like this allow access to remote volcanoes, and provide new methods to monitor potentially dangerous volcanoes.

V42C-1034 1330h POSTER

Thermal Time Series of the 2000 Eruption of Bezymianny Volcano, an Attempt at Thermal Interferometry

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Discovery of precursors to explosive volcanic eruption in satellite imagery is clearly of importance for hazard mitigation. Currently, in order to be detected with satellite imagery, thermal precursors must be fairly pronounced, on the scale of tens to hundreds of meters in size, and tens of degrees over background signals. More often than not, these "precursors" represent some low level of eruptive activity. Detection of a subtle, long-term change in surface temperature at volcanoes using satellite imagery has until now, been unattainable. The goal in this project was to develop a method for thermal interferometry, to compare exactly matched imagery of known past temperatures (presumably at a dormant state) to a newer image (at a restive state), such that weak signals (on the order of 5 degrees or less) can be detected. To test this method, Bezymianny volcano in Kamchatka was chosen. Recently this volcano erupts 2 to 3 times a year, thus should provide a clear thermal signal. A long term archive of imagery from this volcano is available at the Geophysical Institute of the University of Alaska Fairbanks. Over 90 images from the Fall of 1999, while Bezymianny was more or less quiet were used to create a composite background temperature image. This image was compared to single images and groups of images during the activity in 2000. In general, thermal changes were easily spotted in the new imagery at Bezymianny, though it is unclear whether the technique is superior to conventional detection methods by comparing the hottest point near the volcano to a long-term temperature curve. However, the method did detect a faint thermal signal at nearby Kliuchevskoi volcano, which was not detected using other techniques. It is unclear whether this signal at Kliuchevskoi is precursory to a new period of eruption, though it does represent a slight increase over its normal restive state. Advanced Very High Resolution Radiometer (AVHRR) data was used to for this study, due to its availability and high temporal resolution, offering several images daily of the region over nearly 10 years. However the spatial resolution of AVHRR is poor (ca. 1.1 km at nadir), and likely is too coarse for the scale of most precursory thermal changes. The next step of this project is to use higher resolution data, such as ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) or Landsat Enhanced Thematic Mapper, and to acquire background data and eruption imagery pairs.

V42C-1035 1330h POSTER

Volcanic Hazards of San Miguel Volcano, El Salvador–Initial Work

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San Miguel is a Holocene volcano (2130 m) on the volcanic front that has erupted mafic lavas and tephras in small VEI 2 events numerous times in the past 300 years. The city of San Miguel, El Salvador's second largest city (∼300,000) and the economic center of eastern El Salvador, is built 11 km away on the lowermost northeastern flank of the volcano, 2000 m below its summit. A few large towns are built on the west and southwest flanks including San Jorge, San Rafael Oriente, and El Transito. The Pan American and Coastal highways cross the lowermost northern and southern flanks respectively. Coffee plantations cover a large portion of the northern flank whereas the southern flank is mostly ranch land. Historic lava flows from San Miguel occurred between 1699 and 1884 and were mainly erupted from flank vents. Ash fall associated with historic flank eruptions has been reported up to 20 km from the volcano, and fell on the city of San Miguel in 1931. In 1976, small scale fountaining occurred in the summit crater and produced minor ash fall within a few km of the crater. Recently, small debris flows composed mostly of scoria have caused property damage on the northwestern flank of the volcano. Based on its historic activity and its current seismicity, gas emission and rock alteration, San Miguel is perhaps El Salvador's most likely candidate for hazardous activity. We are beginning a hazard study for San Miguel volcano that includes assessment of the hazards from lava flows, ash falls, pyroclastic flows, debris flows, and debris avalanches. This study is important to El Salvador, where volcanic risk is ubiquitous and poorly quantified. As an initial step we have sampled and analyzed 75 samples of lavas, tephras, and pyroclastic flow deposits from the volcano and its vicinity. These analyses indicate that the exposed portion of the cone consists exclusively of basalts and basaltic andesites.

V42C-1036 1330h POSTER

Seasonality of Volcanic Eruptions

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An analysis of volcanic activity in the last three hundred years reveals that the frequency of onset of volcanic eruptions varies systematically with the time of year. We analysed the Smithsonian catalogue of more than 3200 subaerial eruptions recorded during the last 300 years. We also investigated continuous records, which are not part of the general catalogue, of individual explosions at Sakurajima volcano (Japan, 150 events per year since 1955) and Semeru (Indonesia, 100,000 events during the period 1997-2000).

A higher proportion (as much as 18 percent of the average monthly rate) of eruptions occur worldwide between December and March. This observation is statistically significant at above the 99 percent level. This pattern is independent of the time interval considered, and emerges whether individual eruptions are counted with equal weight or with weights proportional to event explosivity. Elevated rates of eruption onset in boreal winter months are observed in northern and southern hemispheres alike, as well as in most volcanically-active regions including, most prominently, the 'Ring of Fire' surrounding the Pacific basin. Key contributors to this regional pattern include volcanoes in Central and South America, the volcanic provinces of the northwest Pacific rim, Indonesia and the southwest Pacific basin. On the smallest spatial scales, some individual volcanoes for which detailed histories exist exhibit peak levels in eruption activity during November-January.

Seasonality is attributed to one or more mechanisms associated with the annual hydrological cycle, and may correspond to the smallest time-scale over which fluctuations in stress due to the redistribution of water-masses are felt by the Earth's crust. Our findings have important ramifications for volcanic risk assessment, and offer new insight into possible changes in volcanic activity during periods of long-term changes in global sea level.

V42C-1037 1330h POSTER

GPS Measurement of Crustal Deformation associated with the 2001 eruptions of Mayon Volcano, Philippines

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We present preliminary results from a new GPS crustal deformation monitoring system deployed in response to ongoing volcanic activity at Mayon Volcano, Philippines. Mayon is one of the most active of the Philippine volcanoes, with over 40 historic eruptions, and major recent eruptions in 1984, 1993, 1999, and 2000. Its previous eruptions have ranged from Strombolian lava to Plinian ash eruptions, frequently generating pyroclastic flows and lahars, both of which have caused significant loss of life. The current eruptive sequence began with small Strombolian eruptions and the appearance of a volcanic dome near the volcano's summit crater early this year. Minor ash eruptions occurred in January and May of this year, culminating in a series of major explosive eruptions in June-July, 2001. The GPS measurements augment a monitoring network of three electronic tiltmeters, one water-tube tiltmeter, four precise leveling lines, six EDM baselines, and seven telemetered seismic stations. The tilt and EDM data show systematic long-term variations associated with the current eruptive sequence: a period of slow inflation from Nov 2000 - May 2001, followed by a period of deflation May-July 2001, leading up to the June-July eruptive sequence. The GPS system includes three continuous dual-frequency GPS sites, 9 campaign sites observed in static and rapid-static mode, and a 4-station kinematic survey line on the northwest flank of the volcano. Continuous sites include one station located on the northeastern flank 3.5 km from the summit crater and one each on the northeastern and southeastern flanks, at distances of 8 and 11 km, respectively. The continuous network was installed on July 21, shortly before a large (12 x 10^6 m^3) lava/pyroclastic eruption of 26 July 2001. At the time of this writing, we have processed the first 20 days of continuous GPS data. The data show relatively stable behavior, with coordinates showing RMS scatter of < ±4-5 mm (RMS) in the baseline length and ±9-14 mm in the vertical. We observe no statistically significant variation in baseline length or height following the July 26 eruption. This relative stability suggests that either (1) the eruption tapped a magmatic source smaller than 12 x 10^6 m^3, (2) a deep magma source resulting in distributed deformation, (3) a very localized near-surface source close to the volcano's summit, or (4) the magma chamber was able to recharge from a deeper source at time scales less than a few hours.

V42C-1038 1330h POSTER

Rock Strength and Stability Modeling Studies of Mt. Shasta Volcano, California

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Mt. Shasta, California rises to 4316 m making it the second highest volcano in the Cascade Range. Approximately 300,000 to 380,000 years B.P. a catastrophic landslide occurred on the ancestral edifice of Mt. Shasta. The deposit from this failure covers an area of approximately 675 km^2 with a volume of about 45 km^3 and is one of the largest Quaternary landslides in existence (Crandell, 1989). The failure deposit forms numerous hummocks formed from intact blocks of the ancestral edifice that remained intact during transport. A matrix facies of fine-grained material from the ancestral valley floor in addition to weaker material from the edifice is found in the intervals between the blocks. Our research approach is to view the landslide deposit as a model for the type of failure that is possible from the current edifice of Mt. Shasta.

Mt. Shasta is formed from four separate volcanic episodes the oldest of which is thought to be over 100,000 years old, and post dates the Shasta Valley debris avalanche deposit (Crandell, 1989). AVIRIS data shows that each eruptive episode has corresponding areas of alteration, which significantly decreases the strength of the rock due to the presence of clay minerals. Uniaxial compressive strength of the highly altered rock is 4-6 MPa in comparison to unaltered material with a uniaxial compressive strength of approximately 150 to 200 MPa. Measuring discontinuity orientations within the volcano shows two major structural trends. An N-S and a E-W fracture system. Numerical modeling of Mt. Shasta and Shastina utilizing structural and strength data obtained from the field and laboratory investigations indicates different edifice failure scenarios. The weakest areas of the edifice occur at Shastina due to the placement of domes and subsequent contemporaneous alteration of domes and dome boundaries and and in the SE area of Mt. Shasta in the Konwakiton Glacier and Mud Creek region.

V42C-1039 1330h POSTER

Bayesian Inversion of Vertical Displacements at Mt. Etna in the Period 1994-1998: Evidence for Intrusive Phenomena Causing the 2001 Eruption

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We have developed a Bayesian method for the inversion of static ground deformations at volcanic areas. The method allows to infer the conditional probability density on the location and mechanism of point sources representing volcanic phenomena (isotropic strain nuclei, tensile faults) embedded in homogeneous, elastic media. The method has been tested with simulated and real data from volcanic areas. We have analysed, with this method, vertical displacement recorded at Mt. Etna (Southern Italy) from 1994 to 1998, by high precision levellings. Measurements in such a period have been carried out yearly, and resulting displacements have been analysed both in consecutive periods and in the cumulative one. Measurements periods 94-95 and 97-98 show significant uplift, of several centimeters. The maximum cumulative displacement amounts to 7 cm., with a trend similar to each of the two periods 94-95 and 97-98. The shape of displacement is well approximated by a circular simmetry, thus allowing to hypothesise an isotropic overpressure model (Mogi, 1959) as the source, simulating magma intrusion at shallow depth. The application of the inverse method gives the most probable location at about 4.5 Km of depth (b.s.l.) at about 3 Km North from the central craters. The 95% of probability density is concentrated within a radius of about 0.5 Km on the horizontal, 1 Km on depth. The obtained results give important insight on the interpretation of the recent eruptive episodes. In particular, magma intrusion volume estimates agree well with erupted volumes.

V42C-1040 1330h POSTER

Models for the Filling of Crater Lake, Oregon

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Crater Lake partially fills, to a depth of 593 m, the 10-km-diameter, 1200-m-deep caldera formed by collapse of Mount Mazama volcano. The lake receives water from direct precipitation and inflow from the caldera walls and loses water by surface evaporation and leakage. No streams flow from Crater Lake. A high-resolution multibeam echo sounding survey of the lake floor conducted in 2000 (Gardner et al., 2001) revealed seven drowned beaches between 1849 and 1878 m elevation (reference lake elevation is 1883 m). The beaches are thought to reflect drier periods in the lake's history since the climactic, caldera-forming eruption of Mount Mazama, approximately 7,700 years ago. The shallowest drowned beach at 1878 m represents the deepest part of a wave-cut platform up to 100 m wide, substantially wider than any of the beaches, where erodible talus or intensely altered rocks are present. The great width of the platform compared to the width of the drowned beaches indicates that the lake has

mostly been near its current level during the lake's history. Unambiguous evidence of former highstands above 1883 m has not been reported. In order to explain the occurrence of the drowned beaches and their relatively narrow depth range, leakage through the caldera walls must vary with depth and cannot occur just at the lake bottom or at the modern lake level. A reasonable model is that leakage is proportional to elevation above the bottom of the lake. Recognition that there is a thick layer of relatively permeable debris resting on glaciated lava in the northeast caldera wall above an elevation of 1845 m suggests a variant of this model where leakage is proportional to elevation above 1845 m. Climate studies indicate that Crater Lake began to fill during a dry period. Assuming that precipitation at that time was 70% of modern and that the beach at 1853 m (the deeper beach is somewhat suspect) corresponds to this amount of precipitation, a combination of the above leakage models is necessary to match these values. The history suggested by the combination model estimates that the lake filled to 1853 m in around 800 years. The lake filling model provides a chronology for postcaldera andesitic volcanism because volcanic landforms, 98% of their volume hidden beneath the lake's surface, document eruptions at several prior lake levels ending when the lake reached ∼1805 m elevation.

J. V. Gardner et al. 2001, USGS Water Resources Investigations Report 01-4046; http://walrus.wr.usgs.gov/pacmaps

V42C-1041 1330h POSTER

Crater Lake Revealed: Using GIS to Visualize and Analyze Postcaldera Volcanoes Beneath Crater Lake, Oregon

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Crater Lake, Oregon, partially fills the caldera that formed ∼7,700 years ago by the eruption of 50 km^3 of mainly rhyodacitic magma and collapse of Mount Mazama. Prior to the climactic event, Mount Mazama had a 400,000-year eruptive history, much of which was like those of other Cascade volcanic centers such as Mount Shasta. Since the climactic eruption, there have been several less violent, smaller eruptions within the caldera itself. Until a recent bathymetric survey, relatively little was known about the character and timing of these eruptions because their products are obscured beneath Crater Lakes surface.
In the summer of 2000, the lake bottom was mapped with a high-resolution multibeam echo sounder (Gardner et. al., 2001), providing a 2m/pixel view of the lake floor from its deepest basins virtually to the shoreline. Using Geographic Information Systems (GIS) applications, the bathymetric data has been visualized and analyzed (aided by images and samples obtained with the manned submersible *Deep Rover*, sediment cores and dredged rocks, and detailed geologic mapping of Mount Mazama) to determine a geologic map of the lake bottom, a history of lake filling (Nathenson et. al., 2001), and volumes, times, and rates of postcaldera eruptions. These calculations have been used to assemble a geologic history for Crater Lake from the time of caldera formation to present day.
Postcaldera eruptions have been both subareal and subaqueous, and were well underway within about 90 years after the climactic eruption, beginning with andesitic lava flows from the Wizard Island and central platform volcanoes. The eruptive history of the Wizard Island volcano is divided into three periods defined by former shorelines where subaerial flows entered the lake, quenched rapidly, and fractured, forming lobate deltas and breccia slopes. The shorelines are visible in slope and shaded-relief images of the lake floor created with GIS. The lake filling model suggests that these shorelines formed at ∼90, 250, and 480 years after the lake began to fill. Combining volume calculations determined with GIS and age information from the lake filling model, oldest to youngest Wizard Island minimum eruption rates are $8.4x10^6$ m^3/yr, $6.5x10^6$ m^3/yr, and $3.6x10^6$ m^3/yr. These are comparable to rates calculated for the central platform volcano using the same approach. The minimum eruption rate for the entire 4 km^3 of postcaldera andesite erupted from ∼90 to 480 years after caldera formation is $8.4x10^6$ m^3/yr, which is comparable to historic rates of lava effusion at arc volcanoes. The cessation of postcaldera volcanic activity at Crater Lake, ∼4,900 years ago, is marked by subaqueous extrusion of a 0.074 km^3 rhyodacite dome on the east flank of Wizard Island..V. Gardner et. al., 2001, USGS Water Resources Investigations Report 01-4046; http://walrus.wr.usgs.gov/pacmaps. Nathenson et. al., 2001, Models for the Filling of Crater Lake, Oregon (this meeting)

URL: http://walrus.wr.usgs.gov/pacmaps

V42C-1042 1330h POSTER

An Early Holocene Eruptive Period at Mount Rainier, Washington

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Tephrochronologic studies indicate that the Cowlitz Park eruptive period at Mount Rainier began about 7500 years ago and continued intermittently until about 6800 years ago. Stratigraphic evidence suggests that Cowlitz Park time comprises four distinct eruptive episodes, each of which occurred during a relatively brief interval. The eruptions produced subplinian falls, several small ash falls, pyroclastic flows, and lahars, the largest of which swept down the White River valley to Puget Sound lowland. Tephra layers are of two types: vesicle rich (chiefly pumice lapilli, scoria, and ash) and vesicle poor (chiefly fine-grained glass and lithic fragments). Pumice and glass shards in vesicle-rich deposits are microlite-poor and derive from larger explosive eruptions. Glass shards in vesicle-poor ashes have variable microlite contents and derive from smaller explosions, or from ash clouds that billow up from block-and-ash pyroclastic flows. Although the Pleistocene record indicates considerable effusive activity at Mount Rainier, no record remains of lavas that might have erupted during Cowlitz Park time.

The oldest eruption, ca 7500 cal yr BP, produced vesicular tephra "A," distributed to the east, with a volume of 5 x 10^6 m^3. Layer A is pumiceous, but fine-grained, glassy layers, suggestive of ash-clouds derived from pyroclastic flows, bracket it stratigraphically. About 7300 cal yr BP, within a short interval of time, a more complex eruptive episode occurred that produced a subplinian fall, at least 3 minor ash layers and an avalanche of hydrothermally altered rock on the south flank of the volcano that generated a lahar. The subplinian layer, "L," was among the most voluminous in the Holocene 30 x 10^6 m^3 at Mount Rainier. This tephra occurs to the southeast and chiefly contains pumice along with subordinate, juvenile, lithic clasts. Related fine-to-coarse-grained ash layers derive from small explosions that occurred shortly before and after the eruption of layer L.

Another subplinian eruption occurred ca 7000 cal yr BP and deposited tephra layer "D" to the east, 50 x 10^6 m^3. Near the volcano, ballistic "D" scoria bombs are common. The presence of both mafic scoria and silicic pumice lapilli within the tephra indicate that magma mingling at depth influenced the D eruption. About 6800 cal yr BP, the last eruption of the period produced a 2-3 x 10^6 m^3 tephra (layer N) that was distributed east to northeast. Layer N is pumiceous, but, as with layer A, it occurs stratigraphically between fine-grained, glassy layers, suggestive of ash-clouds derived from pyroclastic flows. Radiocarbon age control suggests that large ca 10^8 m^3 lahars occurred in the White River drainage during both of these last two eruptive episodes and that the largest flowed at least 70 km downstream.

V42C-1043 1330h POSTER

Late Holocene Eruptions of Mount Rainier, Washington

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Detailed stratigraphy, more than 20 radiocarbon ages, and paleomagnetic secular variation measurements indicate that eruptions of Mount Rainier clustered in three major periods during the past 3000 years. Products include a plinian fall deposit, several vulcanian falls, several fine ash falls that are associated with block-and-ash flows, and lahars that descended all major drainages that head on the volcano. Tephra layers are of two types: vesicle rich (chiefly pumice lapilli, scoria, and ash) and vesicle poor (chiefly fine-grained glass and lithic fragments). Pumice and glass shards in vesicle-rich deposits are microlite-poor and derive from explosive eruptions. Glass shards in vesicle-poor ashes have variable microlite contents and derive from minor explosions, or from ash clouds that billow up from block-and-ash pyroclastic flows. These findings contrast with those of previous studies that document only two eruptions, each associated with a pumiceous tephra layer, during the last 3000 years.

The oldest eruptive period, called Summerland, began after 2700 cal yr BP with a vesicle-poor tephra and a collapse of hydrothermally altered rock on the west flank of the volcano that generated the Round Pass mudflow. Lava flows, fine ash falls and a pyroclastic flow erupted ca 2400 to 2500 cal yr BP. Intermittent eruptions produced more fine-grained ash falls, a possible pyroclastic flow and more lahars, then culminated in the plinian "C" fall to the NE and large lahars that flowed south, southeast, and west about 2200 cal yr BP. The Summerland period ended before 1600 cal yr BP with minor fall deposits and lahars.

About 1000 cal yr BP, the Deadman Flat eruptions produced large lahars that contain distinctive prismatically-jointed glassy clasts, interpreted as juvenile components from pyroclastic flows, and co- ignimbrite ash in the headwaters of the White River. The lahars descended valleys to the NE and flowed 100 km to Puget Sound. Aggradation shortly after emplacement of the lahars filled lowland valleys to depths of 1 to more than 10 meters in the Duwamish, White and Puyallup River valleys and buried tidal flats in what are now the South Seattle suburbs near Boeing Aircraft Co.

Between 600 and 400 cal yr BP, numerous lahars of the White River period, including the alteration-bearing Electron Mudflow, descended the NE, S, and W sides of the volcano. No tephra layers are known for this period, but a lahar in the White River drainage contains distinctive, moderately inflated, glassy clasts, interpreted as juvenile, and eruptions are a likely cause of the edifice-wide lahars during this time period. The last eruptions at Mount Rainier were minor events that occurred between AD 1830 and AD 1850 (X tephra) and in AD 1892.

V42D MC: Hall D Thursday 1330h

Explosive Volcanism: Flows and Falls

Presiding: **C Wilson,** Oxford University

V42D-1044 1330h POSTER

Fractal Spectrum Technique for Quantitative Analysis of Volcanic Particle Shapes

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The shapes of volcanic particles reflect numerous eruptive parameters (e.g. magma viscosity, volatile content, degree of interaction with water) and are useful for understanding fragmentation and transport processes associated with volcanic eruptions. However, quantitative analysis of volcanic particle shapes has proven difficult due to their morphological complexity and variability. Shape analysis based on fractal geometry has been successfully applied to a wide variety of particles and appears to be well suited for describing complex features. The technique developed and applied to volcanic particles in this study uses fractal data produced by dilation of the 2-D particle boundary to produce a full spectrum of fractal dimensions over a range of scales for each particle. Multiple fractal dimensions, which can be described as a fractal spectrum curve, are calculated by taking the first derivative of data points on a standard Richardson plot. Quantitative comparisons are carried out using multivariate statistical techniques such as cluster and principal components analysis. Compared with previous fractal methods that express shape in terms of only one or two fractal dimensions, use of multiple fractal dimensions results in more effective discrimination between samples. In addition, the technique eliminates the subjectivity associated with selecting linear segments on Richardson plots for fractal dimension calculation, and allows direct comparison of particles as long as instantaneous dimensions used as input to multivariate analyses are selected at the same scales for each particle. Applications to samples from well documented eruptions (e.g. Mt. St. Helens, Tambora, Surtsey) indicate that the fractal spectrum technique provides a useful means of characterizing volcanic particles and can be helpful for identifying the products of specific fragmentation processes (volatile exsolution, phreatomagmatic, quench granulation) and modes of volcanic deposition (tephra fall, pyroclastic flow, blast/surge).