variations in transpression and processes of terrane accretion. Deformation is strain and displacement partitioned throughout the orogen; transcurrent motion is focused along discrete strike-slip faults, and shortening is distributed among reverse faults and folds with sub-horizontal axes. Plunging folds accommodate horizontal shortening and extension in the western part of the orogen. Segment boundaries extend across the Yakutat terrane where they coincide with the courses of huge piedmont glaciers that flow from the topographic backbone of the range onto the coastal plain. The eastern segment is marked by strike-slip faulting along the Fairweather transform fault and by a narrow belt of reverse faulting where the transpression ratio is 0.4:1 shortening to dextral shear. The transpression ratio is 1.7:1 in the central part of the orogen where a broad thin-skinned fold and thrust belt deforms the Yakutat terrane south of the Chugach-Saint Elias (CSE) suture. Dextral shearing is accommodated by strike-slip faulting beneath the Seward and Bagley glaciers in the hanging wall of the CSE suture, and partly by reverse faulting along a structural belt that cuts across the Yakutat terrane along the western edge of the Malaspina Glacier and links to the Pamplona fold and thrust belt offshore. Deformation along this segment boundary is probably also driven by vertical axis bending of the Yakutat microplate during collision. Subduction & accretion in the western segment of the orogen causes refolding of previously formed structures when they are emplaced into the upper plate of the Alaska-Aleutian mega-thrust. Second phase folds plunge at moderate to steep angles and accretion is marked by only modest amounts of uplift. The structural boundary between the central and western segments of the orogen localizes the course of the Bering piedmont glacier. The structural segments coincide with subdivisions in historical seismicity, particularly ruptures of great to large magnitude earthquakes. The results of this structural study provide the requisite geological framework to design new-generation geophysical monitoring systems to study active deformation within the orogen.

## S22D-10 1605h

### Crustal structure of North America and the Adjacent Ocean Basins

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A compilation of seismic data is presented to construct maps of properties of the Earth's crust and mantle. We present new maps of the seismic properties of North America and the surrounding ocean basins, including contour maps of: 1) crustal thickness (hc); 2) average crustal p-wave velocity (Pc); 3) average p-wave velocity of the consolidated or crystalline crust (Pcc); and 4) sub-Moho p-wave velocity (Pn). Our crustal thickness map for North America and the surrounding ocean basins was recently updated using a database of about 2000 data points. One new feature of this map is an extension of the thin crust of the Basin and Range Province into Western Canada. We also find a close correspondence between high average crustal velocity and accretionary and magmatic orogenies.(e.g., Trans-Hudsonian, Grenvillian, Acadian, Appalachian, the Cascades, and the Alaskan Range). In contrast, there are a number of interesting anomalously low average crustal velocities in the Basin and Range Province, the Snake River Region, and the Northwest Territories of Canada. Many of these are regions of recent extension or hotspot activity.

## S22E MC: 306 Tuesday 1530h

## Volcano Seismicity and Structure II

*(joint with T, V)*

***Presiding:*** **C Wolfe,** University of Hawaii

## S22E-01 1530h

### High Precision Relocations of Deep Hawaiian Earthquakes

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The abundant earthquakes in Hawaii provide key information on the nature of magmatic and tectonic processes at this oceanic hotspot. Here, we present the results of a project to relocate deep earthquakes (> 14 km) recorded on the United States Geological Survey (USGS) Hawaiian Volcano Observatory (HVO) Network. While many deep earthquakes are believed to reflect pathways of magma movement, the hypocenter distributions suggest additional processes may play a role. We are pursuing two lines of research to obtain a more accurate picture of deep seismicity characteristics. First, both the source specific station term method of Richards-Dinger and Shearer (2000) as well as the double difference method of Waldhauser and Ellsworth (2000) are being applied to relocate earthquakes dating back to 1974 using HVO catalog travel time picks. These methods help remove the biasing effects of velocity heterogeneity and thus improve the relative locations between nearby earthquakes. Second, for specific target areas in space and time, we are measuring accurate differential arrival times using waveform cross-correlation, which can be used to further refine hypocenter locations. At present, we have applied cross-correlation analysis to two areas: 1) a 1994 $m_b$ 5.3 30-km deep earthquake and its aftershocks, which occurred slightly south of Kilauea, and 2) all deep earthquakes recorded at HVO in 1997. We find that a significant percentage of aftershocks following the 1994 earthquake are strongly correlated multiplets and that a double difference solution using catalog and cross correlation data yields a horizontal line of seismicity, consistent with a horizontal fault plane. This region has also experienced several previous $m_L \sim 4.5$ earthquakes, suggesting that a mantle fault has been active over the past few decades. In contrast, only a small percentage of deep earthquakes recorded in 1997 are multiplets that provide correlated waveforms, and we find these multiplets occur in areas scattered beneath the island of Hawaii.

## S22E-02 1545h

### Preliminary Relocations on Kilauea's Southwest Rift Zone and Western South Flank

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Approximately 1500 earthquakes from the archives of the U.S. Geological Survey's Hawaiian Volcano Observatory (HVO) were relocated using the double-difference relocation algorithm of program hypoDD. The earthquakes, from Kilauea's southwest rift zone and western south flank, occurred during the years 1986-99. The relocations have revealed a well-defined basal decollement that mirrors the surface topography of the volcano. The decollement is first detectable near the island of Hawaii's shoreline at a depth of approximately 5 km, and slopes inland to a depth of 10 km near the summit of Kilauea. Though a basal decollement is not a new discovery on Kilauea, the newly-relocated earthquakes in this section of the volcano provide a superior image of the decollement and other details of the south flank's complex structure. The western south flank of Kilauea is riddled with normal faults in two major fault zones, the Koae Fault Zone to the north, and the prominent Hilina Fault System to the south, which forms spectacular fault scarps near the southeastern coast of the island. Relocations of earthquakes on the south flank indicate that many of the normal faults, particularly those on the upper Hilina Fault System, extend to a depth of 7-8 km and join the decollement.

For this type of study, in which there is a dense network of stations recording high-quality digital data and a well investigated regional velocity structure, HYPODD has proven to be an excellent method of relocating earthquakes. HYPODD may be used strictly with catalog data, with waveform cross-correlation results, or with a combination of both catalog and cross-correlation data. The relocations for this study were performed using catalog data from the HVO archives and a simple 2-dimensional velocity model of the region. Cross-correlation data will soon be incorporated, and it is expected that the new data will further improve the locations of these earthquakes.

## S22E-03 1600h

### High Precision Locations of Seismic Events at SE Flank of Mount Etna: Characteristics of the Seismogenetic Structures

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On 9 of January 2001 the INGV seismic network of Catania (Italy) recorded a seismic swarm of about 60 earthquakes with 1.0>Md>3.6, and nearly identical seismograms. The main shock caused damage to the town of Zafferana Etnea 2.5 km distant from the epicenter located on SE flank of the volcano.

Some other events with similar waveform forecasted (up to 2 months before) and followed (for about one month) this swarm; moreover a check of Mt. Etna SE flank seismicity, starting from 1994, has permitted to identify a cluster of 6 multiplets recorded on August 1995 whose seismograms are strongly coherent with the January 9, 2001 ones. Thus we recognize for the first time the occurrence of seismic events on Mount Etna with nearly identical sources separated by years.

We applied a cross-spectral technique that allows to obtain the relative relocation of events within a multiplet to at least an order of magnitude higher precision than is typically possible with traditional techniques.

The results describe clearly the geometry of the seismogenetic structure; the events lie on planes oriented ENE-WSW that are coincident with one of the planes of the focal mechanism obtained by first-arrivals polarities. This alignment is coherent with one of the main regional tectonic trends that characterize the Mt. Etna area

The multiplets analysis has allowed to recognize, on SE flank, a right-lateral strike seismic source along ENE-WSW fault plane, 4 km deep, time repeated and able to produce strong releases.

## S22E-04 1615h

### Combined Absolute/Relative Hypocenter Determination and Moment Tensor Inversion of a VT-B Event Cluster Before the 1998 Eruption of the Mt. Merapi Volcano (Java)

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In the ongoing Indonesian-German MERAPI project the seismic signals at Merapi volcano are recorded continuously since July 1997 with a combined seismic network-array approach. With this network it was possible to record the seismicity before the onset of the eruption in July 1998 with a high dynamic and broad frequency range. The automatic standard analysis of the recorded seismic data before the first of two larger pyroclastic density flows emphasized the importance of a seismic swarm of VT-B type events in order to forecast the location of the newly formed lava lobe during this eruptive phase.

To improve the location accuracy, we relocate these events using an extended cluster analysis technique. We first estimate the amount of events in three different seismic clusters. After this we estimate the relative onset times of all event combinations within one cluster using the SmoothedCOherencyTransform algorithm. Further we use the amplitude of the computed cross-correlation coefficients of each event-event waveform pair to further restrict our hypocenter constrain. In the final step we invert iteratively all estimated travel times, the relative travel times within the different arrays and the correlation coefficients in one single matrix. The resulting high precision hypocenter determination of the distinct clusters indicate a small source volume in the intersection of a old crater floor and the active part of Mt. Merapi.

The high precision in hypocenter determination make a detailed analysis of the source mechanisms of these VTB events feasible. We use a point source full moment tensor inversion and simple source time functions to invert for the source mechanism. Greens functions are calculated with the reflectivity method and local 1D models based on refraction on different scales. The bias in the results due to not modelled topography and 3D-structure is estimated using a bootstrap approach.

## S22E-05 1630h

### Temporal evolution of a hydrothermal system in Kusatsu-Shirane Volcano, Japan, inferred from the complex frequencies of long-period events

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We present a detailed description of temporal variations in the complex frequencies of long-period (LP) events observed at Kusatsu-Shirane Volcano during the period from August 1992 through January 1993. We use the Sompi method to determine the complex frequencies of the dominant spectral peaks of LP events from the tails of the LP waveforms. The observed temporal variations in the complex frequencies can be divided into three periods. During the first period, before September 5, the dominant frequency rapidly decreases from 5 to 1 Hz, and Q of the dominant spectral peak remains roughly constant with an average value near 100. During the second period, between September 5 and December 6, the dominant frequency gradually increases up to 3 Hz, and the associated value of Q gradually decreases from 160 to 30. During the third period, after December 6, the dominant frequency increases more rapidly from 3 to 5 Hz, and Q shows an abrupt increase at the beginning of this period and then remains roughly constant with an average value near 100. Such temporal variations can be consistently explained by the dynamic response of a hydrothermal crack to a magmatic heat pulse. During the first period, crack growth occurs in response to the overall pressure increase in the hydrothermal system caused by the heat pulse. During this time of crack formation, the crack may be filled with either a wet misty gas or a water foam. Once crack formation is complete, heat gradually changes the fluid in the crack from a wet misty gas to a dry gas during the second period. As heating of the hydrothermal system gradually subsides, the overall pressure in this system starts to decrease, causing the collapse of the crack and allowing cooler water to seep in from the surrounding region during the third period. This influx of colder water changes the fluid in the crack from a dry gas to a wet misty gas or a water foam.

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## S31A MC: Hall D Wednesday 0830h

### Subsurface Imaging and Fractures in Reservoirs and Sediments *(joint with T)*

***Presiding:*** **S H Harder,** UTEP

## S31A-0574 0830h POSTER

### Geophysical diffraction tomography and waveform inversion: Applications to high resolution seismic data

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We apply two different techniques to analyze high resolution seismic data from surface and borehole measurements made at a groundwater contamination site at Hill Air Force Base, Ogden, Utah. Two vertical seismic profiles and surface data were recorded simultaneously in and between two 15m deep boreholes separated by 21m. The seismic source was a 223 rifle fired on the surface between the two boreholes, generating signals with energy up to ~300Hz. The size of the target area is roughly the order of a few mean wavelengths in the dataset. The relatively large ratio of mean wavelength (~5m) to the scale of structural detail in this high-resolution experiment (<1m) necessitates the application of diffraction tomography and waveform inversion methods.

In the first method, we use a form of geophysical diffraction tomography based on the modified Kaczmarz method so that uncertainty in the data can be taken into account and other constraints can be incorporated. The forward model is a linearized Born or Rytov approximation formulated in the frequency domain. The inverse model is obtained using the modified Kaczmarz method where the relaxation parameter is a function of weights estimated from the signal/noise ratio in the data set. Using different weights the image is generated iteratively by back projecting misfits in the data space into velocity corrections in the model space. In theory, multiple-frequencies and non-uniform data sampling can be handled easily.

In the second technique, full waveform inversion, the inverse problem is posed as nonlinear data fitting where the unknown parameters are solved by minimizing the misfit between the predicted data and the observed data. A gradient-type approach is applied to solve these problems in which the Jacobian and its adjoint are calculated for given model and data vectors. We present an explicit finite difference time stepping scheme to compute the forward model and its adjoint. Waveform data fitting driven by finite difference simulations can be based on different physical modeling assumptions, from acoustic to viscoelastic propagation. Our finite difference class defines an operator in the sense of the Hilbert Class Library (HCL), a C++ software package for optimization (Cockenback, and Symes, 1996). A wide range of gradient type inversion algorithms using HCL as a platform can be tested.

URL: http://terra.rice.edu

## S31A-0575 0830h POSTER

### High Resolution 3-D Seismic Reflection and Tomography Experiments at a Groundwater Contamination Site

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In August 2000 we conducted 3-D surface seismic reflection and tomography experiments at Operable Unit 2 (OU2) at Hill Air Force Base, Ogden, Utah. The experiment included 2 vertical seismic profiles and 6 checkshot surveys. OU2 is the site of ongoing remediation to remove dense nonaqueous phase liquids (DNAPLs) contaminating a shallow (< 15 m) water table.

The near-surface geology of OU2 includes unconsolidated sands, silts and gravels that overlie a thick clay aquitard. A paleochannel incised in the top of the clay aquitard acts as a structural trap for contaminants. Although OU2 has been extensively drilled with wells (> 250 in a 5000m$^2$ area), the near-surface geology is insufficiently characterized to allow effective remediation. A pilot 2-D seismic reflection experiment in 1998 demonstrated the viability of using high resolution seismic methods to image the channel at depths < 15m.

The 3-D surveys in 2000 covered an area of 95m by 37m, centered over the paleochannel. We recorded with 612 RefTek Texans, equipped with 40Hz geophones. For 3-D surface reflection we deployed 103 instruments along each of 6 parallel lines. Inline instrument spacing was 0.35m, crossline spacing was 2.1m. A 223 caliber rifle was used as a seismic source, with shots fired at 0.35m intervals in a rotated brick pattern along a swath through the center of the receiver array. The array was rolled 43 times, producing over 4500 shot records.

For the 3-D tomography experiment the Texans were deployed using a staggered 2.8m by 2.1m grid spacing. Six hundred shots were recorded, one adjacent to each receiver, producing offsets greater than 100m.

The shot records contain unusual sources of ambient noise including signals from overflying jets and from remediation pumps operating during the experiment. Most of this noise is below 50 Hz, well below the frequency range of interest (80-300 Hz) for imaging at the resolution required for characterization of the paleochannel ( 0.5m). Preliminary results from the surface reflection and tomography experiments will be presented.

## S31A-0576 0830h POSTER

### Tomographic Imaging of Local Hydrate Concentrations Within a Faulted Gas-Hydrate Reservoir

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Recent studies suggest that increased fluid and methane flux along permeable pathways through the hydrate stability zone (HSZ), such as faults, may evolve into localized regions of concentrated hydrate. Background hydrate concentrations in the HSZ at the Blake Ridge are known to be 4-7% by volume. At Site 997 (ODP Leg 164), a localized concentration of hydrate of nearly 100% (a hydrate plug) was recovered and believed to be associated with a fault. Seismic lines show that the Blake Ridge is pervasively cut by faults extending through the HSZ, and thus significant concentrations of hydrate may be present within these faults. The seismic velocity of methane gas hydrate is 3.7 km/s (compared with 1.7 km/s sedimentary velocity), and so significant local concentrations of hydrate can be detected seismically given data of sufficient resolution. Knowledge of the volumes of hydrate along and near faults may alter estimates for total hydrate present within this and other reservoirs and may influence parameterizations of fluid flux through these systems. We will present results of reflection tomography based on 6-km MCS streamer data spanning a 3.7-km region across Site 997. Guided, automated picks of reflection traveltimes for the seafloor and the BSR (bottom-simulation reflector) from 600 CDP gathers (6.125-m spacing) were fit with 1-D velocity models to develop a starting model for the inversion. Residuals of these 1-D models are small, on the order 1 ms, but correlated. The patterns of the residuals are suggestive of localized velocity anomalies extending through the HSZ. The tomographic inversion results that we will present will image the features giving rise to these residuals.

## S31A-0577 0830h POSTER

### Seismic Characterization of a Gas Hydrate System in the Gulf of Mexico.

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In a joint project in 1998, the U.S. Geologic Survey, University of Mississippi, and U.S. Department of Energy conducted a high-resolution seismic survey to study the Gulf of Mexico gas hydrate environment. The gas hydrate environment under investigation is a focused methane flux system. The gas hydrate formation seems to be linked to a supply of vast quantities of methane and other gases along faults. Around faults, hydrates frequently crop out at the seafloor, which is an indication of a strong supply of hydrate gases. Both Single Channel Seismic (SCS) and coincident Ocean Bottom Seismometer (OBS) data were acquired. The data quality is good, providing substantial ray coverage for 2D tomography.

Initial results indicate free gas beneath the gas hydrate bearing mud diapir, but there is no clear indication of a Bottom Simulating Reflector (BSR). A lack of BSRs despite abundant gas hydrate occurrences appears to be one of the most striking characteristics in the Gulf of Mexico gas hydrate system. The goals of this study are to: (1) derive a 2D velocity-depth model below the shot lines by inverting the reflected and refracted arrivals from the OBS and SCS data simultaneously; (2) if the data permits, estimate the S-wave velocity variation in 1D below the OBSs; (3) use the P- and S-wave velocity model to estimate the lateral and vertical extent of the hydrate formation and free gas; (4) use a multi-component seismic reflection line (10 km to the SW of study area) to correlate the stratigraphy and make a geological interpretation.

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