crustal stress in the Los Angeles region. The goal is to increment the displacement along the edges of the domain and allow earthquakes to control the evolution of the stress field within the volume. A wide variety of seismological and geodetic observations constrain the level of stress, including (1) rupture behavior, such as rupture speed and distribution of slip, inferred from kinematic source inversions of earthquakes, (2) the lack of heat flow found in exposed fault zones, (3) GPS and InSAR observations of plate motion, and (4) the need to support variations in topography and mass density. Comparison of synthetic strong ground motions with recorded motions will also provide feedback into the dynamic friction models.

The model relies on two principle components. Dynamic rupture simulations of earthquakes provide a test bed for evaluating how well various friction models produce realistic rupture behavior and allow computation of the perturbations in the stress field caused by the slip on the fault. Static simulations produce estimates of the background stress field from gravity acting on topography and density variations, strain accumulation due to plate motion, and slip during prior earthquakes. Successive earthquakes within the region and subsequent earthquakes on a single fault will play an important role in discriminating between different friction models.

Our preliminary results have focused on examining the behavior of ruptures with different friction models. We have found that (1) frictional sliding on fault surfaces is a highly nonlinear process that cannot be described by constant traction boundary conditions due to spatial and temporal variations in the magnitude and direction of the friction stress; (2) instantaneous healing of the fault upon termination of sliding accentuates the development of heterogeneity in the stress field and the distribution of slip; and (3) introducing rate-weakening behavior leads to pulse-like ruptures that tend to create stress fields and slip distributions with more heterogeneity for a given stress field than crack-like ruptures.

G31C MC: Hall D Wednesday 0830h

Surface Deformation Associated with Active Volcanism *(joint with T, V)*

Presiding: **F Amelung,** University of Hawaii**; S Owen,** University of Southern California

G31C-0155 0830h INVITED POSTER

Magmatic Activity Beneath the Quiescent Three Sisters Volcanic Center, Central Oregon Cascade Range, USA, Inferred from Satellite InSAR

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Images from satellite interferometric synthetic aperture radar (InSAR) reveal uplift of a broad ~10 km by 20 km area in the Three Sisters volcanic center of the central Oregon Cascade Range, ~130 km south of Mt. St. Helens. The uplift is centered ~5 km west of South Sister volcano, the youngest stratovolcano in the volcanic center. The center has been volcanically inactive since the last eruption ~1500 years ago. Multiple European Space Agency ERS-1 and 2 satellite images from 1992 through 2000, used in this study, were selected based on orbital separation and time of year. Summer and early autumn scenes were necessary to avoid decorrelation from snow cover. Interferograms generated from these images indicate that most if not all of ~100 mm of observed uplift occurred between September 1998 and October 2000. We interpret the uplift as inflation caused by an apparently ongoing episode of magma intrusion at a depth of ~6.5 km.

Geochemical (water chemistry) anomalies, first noted ~1990, coincide with the area of uplift and suggest the existence of a magma reservoir prior to the uplift. High chloride and sulfate concentrations, and a positive correlation between chloride concentration and spring temperature were found within the uplift area, with larger SO_4/Cl ratios in springs at higher elevations. These findings are indicative of a high-temperature hydrothermal system driven by magma intrusions.

The current inflation episode observed with InSAR may lead to an eruption, but the more persistent geochemical evidence suggests that the episode is likely the latest in a series of hitherto undetected magma intrusions. We do not yet know if the inflation has abated, is continuing, or has accelerated since October 2000–we only know that the highest rate of uplift occurred in the last year for which ERS-2 data was available (1999- 2000). In May of 2001, a continuous GPS receiver and seismometer were installed by the USGS within the Three Sisters Wilderness to monitor the uplift.

G31C-0156 0830h POSTER

Horizontal and Vertical Deformation Near Three Sisters Volcanic Center, Oregon, From Leveling, EDM, and GPS

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A broad zone of crustal uplift near the Three Sisters volcanic center, which was detected with SAR interferometry, has been interpreted to result from the accumulation of magma at a depth of 6.5 km during the interval 1998-2000. No useful SAR images of the deforming area have been acquired since late 2000, so it is not known whether the uplift is continuing. Possible ongoing deformation is being tracked by a continuous GPS station located 3.5 km north of the center of uplift, which was installed by the U.S. Geological Survey in June 2001. No significant deformation had been detected through mid-August, but the preliminary station velocity relative to a reference site 50 km to the east is similar to that predicted by inflation of a point source that fits the observed uplift. Several stations in a GPS profile extending north of the uplift along the Mackenzie Pass were resurveyed in August 2001 to determine the rate and pattern of deformation since 1999. These data will help determine corrections for secular tectonic deformation associated with subduction of the Juan de Fuca plate beneath North America. Recovery of four 300-m-long leveling arrays and a 21-station EDM network on nearby South Sister, planned for September 2001, will place limits on local tilt and strain since the initial observations in 1985. New campaign GPS stations will be installed and surveyed in September 2001 to improve spatial and temporal resolution of possible ongoing deformation.

G31C-0157 0830h POSTER

InSAR studies of Hawaiian volcanoes: Initial results

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The Hawaiian volcanoes Kilauea and Mauna Loa are among the most active in the world. Kilauea is has been in near-continuous eruption since 1983 and Mauna Loa erupts on average every 15-30 years. The Hawaiian volcanoes are actively deforming due to transfer of magma into and out of the magma reservoirs, and due to movements along sub-horizontal decollements at the pre-volcano-seafloor. We discuss our JERS-1and ERS-2 InSAR observations which may help constrain this deformation.

A 1993-1998 JERS interferogram shows 22 cm of range decrease on the SE flank of Mauna Loa, roughly consistent with the 1993-1996 campaign GPS measurements. Flank motion has slowed down after this period as shown by 1998-2000 ERS interferograms. At Kilauea southflank deformation contributes only little to the observed range changes because of the viewing geometry of the ERS radar. The ERS intererograms show subsidence of 10 cm/yr in the summit area of Kilauea, consistent with leveling data. We discuss possible mechanisms for the observed subsidence including deflation of Kilaueas magma reservoir, deep dike inflation and degassing. Deformation due to shallow intrusions has also been detected

G31C-0158 0830h POSTER

Edm deformation monitoring at the Colima Volcano before and during the 1997-2000 activity

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The 1997-2000 activity at Colima Volcano began in November 1997 with a series of seismic swarms and deformations of the summit lava dome. This activity reached a climax on 20 November 1998 with the extrusion of lava, accompanied by pyroclastic flows. From 10 February 1999, the explosion activity began and continued up to the time of paper preparation. Summit deformation was detected by Electronic Distance Measurement (EDM) surveys using a single frequency distancemeter DI3000s mounted on a theodolite Wild T2. Distance measurements were carried out from three base stations utilizing nine reflectors located around the volcano edifice. Reflectors were located on three different altitudes at the volcano edifice (3250, 3450, 3850 m).. After the destruction of two summit reflectors in July 1998 we continued the EDM surveys mainly with five reflectors remaining on the north flank of the volcano. EDM distance measurements taken from November 1997 to July 1998 showed maximum cumulative distance change of 0.5 cm/day on the summit reflectors that was interpreted in terms of inflation of the volcanic edifice in response to magma movement towards the surface.. EDM variations recorded in August 1998 February 1999 from reflectors on the north flank of the volcano may reflect further inflation before extrusion of lava on 20 November 1998 and deflation after effusion ceased in February 1999.

G31C-0159 0830h POSTER

Deformation in Long Valley and the Hilton Block, Sierra Nevada, CA from GPS studies.

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Long Valley caldera, California, is a "natural laboratory" for the study of interaction between volcanism and tectonics. The Hilton Block area south of Long Valley caldera has been one of the most seismically active regions in California. The patterns of recent seismicity, however, are difficult to reconcile with the observed regional strain or with stress transfer calculated from simple elastic models of volcanic inflation. Understanding the connections between volcanism and tectonics in this region will require a better understanding of both the kinematics of the Hilton Block and the mechanics of stress transfer within the caldera system.

Annual GPS measurements have been made since 1999 on a growing network of ~35 sites designed to better characterize the both the regional strain rates and the strain rates within the Hilton Block. Our network includes data from 10 recently installed benchmarks and 10 benchmarks without a prior history of survey-mode GPS measurements. As indicated by the two-color EDM network run by the U.S.G.S., the resurgent dome has not inflated significantly during this time period. Therefore the strain measurements should be influenced primarily by the regional tectonics, not magmatic intrusion events. We will present preliminary results from this new network of GPS sites and also continuous GPS sites.

By developing a more detailed picture of the kinematics of the Long Valley region, we can advance our understanding of the mechanical interactions between

volcanism and tectonics. An understanding of the connection between these two processes is imperative for accurate hazards assessment in this and other volcanic regions.

G31C-0160 0830h POSTER

A survey of volcano deformation in the central Andes using InSAR: Evidence for deep, slow inflation

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We use interferometric synthetic aperture radar (InSAR) to survey about 50 volcanos of the central Andes (15-27° S) for deformation during the 1992-2000 time interval. Because of the remote location of these volcanos, the activity of most are poorly constrained. Using the ERS-1/2 C-band radars (5.6 cm), we observe good interferometric correlation south of about 21° S, but poor correlation north of that latitude, especially in southern Peru. This variation is presumably related to regional climate variations.

Our survey reveals broad (10's of km), roughly axisymmetric deformation at 2 volcanic centers with no previously documented deformation. At Uturuncu volcano, in southwestern Bolivia, the deformation rate can be constrained with radar data from several satellite tracks and is about 1 cm/year between 1992 and 2000. We find a second source of volcanic deformation located between Lastarria and Cordon del Azufre volcanos near the Chile/Argentina border. There is less radar data to constrain the deformation in this area, but the rate is also about 1 cm/yr between 1996 and 2000. While the spatial character of the deformation field appears to be affected by atmosphere at both locations, we do not think that the entire signal is atmospheric, because the signal is observed in several interferograms and nearby edifices do not show similar patterns. The deformation signal appears to be time-variable, although it is difficult to determine whether this is due to real variations in the deformation source or atmospheric effects.

We model the deformation with both a uniform point-source source of inflation, and a tri-axial point-source ellipsoid, and compare both elastic half-space and layered-space models. We also explore the effects of local topography upon the deformation field using the method of *Williams and Wadge* (1998). We invert for source parameters using the global search Neighborhood Algorithm of *Sambridge* (1998). Preliminary results indicate that the sources at both Uturuncu and Lastarria/Cordon del Azufre volcanos are model-dependent, but are generally greater than 10 km deep. This depth suggests a potential relationship between the deformation source at Uturuncu and the large Altiplano-Puna Magmatic Complex that has been imaged seismically (e.g. *Chmielowski et al.*, 1999), although the deformation at Lastarria/Cordon del Azufre lies outside the region of lowest seismic velocities (*Yuan et al.*, 2000).

G31C-0161 0830h POSTER

Volcanic and Tectonic Deformation of Unimak Island in the Aleutian Arc

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Unimak Island is located in the central part of the Alaska-Aleutian Arc. It hosts several volcanoes and is part of a complex tectonic setting. It is one of the target areas for the proposed Plate Boundary Observatory. We present results from GPS surveys investigating volcanic and tectonic deformation on the island.

Westdahl volcano, at the southwest end of the island, last erupted in 1991-1992. GPS surveys conducted between 1998 and 2001 show radial displacement and general uplift of the volcanic edifice, indicating inflation. The inflation source is modeled to be at 9 km depth beneath the summit, producing a subsurface volume change of approximately 0.04 km^3/year. This is in agreement with previous results from INSAR studies betwen 1993 and 1998, and shows that Westdahl has been inflating continuously for almost 10 years now. Neighbouring Fisher Caldera has not had recent significant eruptions, but it does have an active hydrothermal system. The GPS data show subsidence of the caldera floor up to 20 mm/year between 1999 and 2001, and horizontal shortening across the center.

In the eastern part of Unimak Island, GPS data indicate that there is no strain accumulation across the arc. This is the same scenario as for the western Shumagin section of the arc extending to the northeast. The situation is different at the western end of Unimak. This area is part of the rupture zone of the 1957 M_W 9.1 earthquake, and strain accumulation currently causes surface deformation. Elastic dislocation modeling is used to constrain the interseismic coupling. The boundary between the uncoupled segment and the coupled segment is probably close to the western end of the island.

G31C-0162 0830h POSTER

Eruptive Activity and Ground Deformation Revealed by Satellite Radar Interferometry at Makushin Volcano, Alaska: 1993 - 2000

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Makushin has been one of the more historically active volcanoes in the Aleutian arc of Alaska, having produced at least 17 explosive eruptions since the late 1700s. Pilot reports in January 1995 and field observations in summer 1996 indicate that a relatively small explosive eruption of Makushin occurred on January 30, 1995. Several independent radar interferograms that span the time interval from October 1993 to September 1995 show evidence of ∼7 cm of uplift centered on the volcano's east flank, which we interpret as pre-eruptive magmatic inflation of a ∼7 km deep source with volume change of 0.022±0.002 km^3. Subsequent interferograms for 1995-2000, a period that included no reported eruptive activity at Makushin, show no evidence of additional ground deformation. This demonstrates that radar interferometry is a powerful technique to study volcanoes in remote and difficult settings, where eruption might have gone undetected or been underestimated. At Makushin Volcano, interferometric coherence at C-band persists for three years or more on lava-flow and rock surfaces covered with short grass or sparsely distributed tall grass. Over most of the pyroclastic deposits, coherence can be maintained for at least one year. Lava and rocks with densely distributed tall grass, and alluvium remain coherent for only a few months, while snow and ice lose coherence within a few days. This suggests that C-band radar interferometry can be an effective tool for studying volcano deformation throughout the Aleutian arc and at other high-latitude sites.

G31C-0163 0830h POSTER

Surface Deformation Caused by a Shallow Magmatic Source at Okmok Volcano, Aleutian Arc

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Okmok Volcano, located on Umnak Island in the eastern Aleutian arc, last erupted in 1997. Okmok consists of a 10 km wide caldera with several cones located inside. Significant surface deformation before, during and after the eruption has been measured using InSAR. However, the area of coherent data has been limited to the northern part of the caldera, with some additional coherent areas along the outer flanks of the volcano. With support from NASDA (National Space Development Agency of Japan) and the International Arctic Research Center, we carried out GPS campaigns in 2000 and 2001 to supplement the InSAR data with 3D measurements of deformation at well-distributed points. We surveyed 24 sites on and around Okmok in 2000, and 31 sites in 2001. As of this date, no SAR data from suitable passes has been acquired in the summer of 2001; if any are acquired, we will also analyze this data.

InSAR data for the period 1997-2000 show what appears to be a radially-symmetric pattern of displacements, consistent with the inflation of a shallow (3-4 km) pressure (Mogi) source located beneath the geoemtric center of the caldera. A deflation source at the same location and depth was inferred from an interferogram spanning the eruption. The 2000-2001 GPS data, on the other hand, show evidence for rapid horizontal extension between sites in center of the caldera. This signal cannot be explained by a Mogi source, and may represent the intrusion of a shallow dike. In addition to this probable dike source, it appears that overall inflation of the volcano continues. The proposed dike extends from roughly the center of the caldera toward the 1997 eruptive vent. In May 2001, a swarm of micro-earthquakes occurred somewhere close to Okmok Volcano (location errors are very large as the closest permanent seismic site is 100 km from Okmok). It is possible that this small earthquake swarm could have been associated with the intrusion of the shallow dike.

G31C-0164 0830h POSTER

Deformation of Grimsvotn volcano, Iceland: 1998 eruption and subsequent inflation

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Grimsvotn is among the most active volcanoes in Iceland, with the most recent eruption in December 1998. The volcano is situated above the central part of the Iceland mantle plume and is nearly covered by the Vatnajokull ice cap. Only a part of the southern caldera rim is exposed above the ice. This makes it possible to follow the magmatic movements of a subglacial volcano. Its deformation has been measured using geodetic GPS measurements 7 times in the time period 1992-2001. The GPS measurements show that the volcano inflated prior to the 1998 eruption. Subsidence of more than 0.15 meters at the GPS-station during the eruption was followed by re-inflation, initially at a rate of 2 cm/month, then declining to 0.5 cm/month. The 1998 eruption caused horizontal displacement of more than 0.25-meters inward to the caldera. After the eruption measured uplift and outward displacement indicates readjustment and inflow of magma. The center of subsidence and uplift originates in the same area in the caldera. Utilizing both the measured horizontal and vertical movements at a single station it is possible to model a Mogi-type point source making an assumption about the horizontal position of the source. The source was assumed to be located under the center of the Grimsvotn caldera. The model of the subsidence indicates a depth of at least 1.6 km. The suggested amount of magma escaping from the chamber during the eruption is comparable to the estimates of the erupted volume. The inflation of the volcano continues, but has not yet reached the pre-eruption level.

G31C-0165 0830h POSTER

3D Deformation at the Coso Geothermal Field - Observations and Models

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Over the past decade, rapid ground deformation has been measured over the Coso geothermal field in Eastern CA using InSAR and GPS. InSAR resolves changes in distance along the line-of-sight (LOS) to the satellite with high spatial coverage. In the Coso geothermal field the maximum LOS displacements are up to 35 mm/yr. The inclination of the LOS is acute (about 20 degrees), hence the majority of the deformation resolved with InSAR is vertical, however LOS displacements are also affected by horizontal displacements. The ratio of the sensitivity of LOS displacements to vertical and horizontal displacements is at most 5 to 2, for horizontal displacements inline with the LOS. GPS is able to resolve large horizontal displacements in this area, leading to the conclusion that the InSAR LOS displacement fields are non-trivially affected by horizontal displacements. Additionally, since the horizontal displacements are large, GPS is also able to resolve vertical displacements. Moreover, the GPS three component velocities are fairly consistent with the LOS displacements from InSAR.

This deformation has been largely attributed to subsidence as fluid is extracted from the geothermal reservoir. The reservoir has been previously modeled as deflating elliptical volumes and as collapsing sills. The elliptical volumes are described as Mogi sources, which are mathematically given as point forces along a line. The collapsing sills are treated as Okada dislocations for finite area faults with pure tensile displacements across them. In both of these dislocation models of the reservoir, the elastic moduli of the rock remains constant with changing fluid pressure. Actual reservoirs are more likely composed of regions of rock permeated with fluid-filled cracks and pores. In such a composite material, changing the pore-fluid pressure changes the elastic moduli of the region. These moduli changes cause the region to deform under loading, thus resulting in observed surface displacements. The surface displacements resulting from models with varying moduli of the reservoir rock are markedly different from patterns of surface displacements resulting from models in which the reservoir is treated as dislocations. For a given reservoir size, the differences in displacements from the various models are clearest in the horizontal displacement field, differing by up to a factor of two. We use finite element models with simple reservoir geometries to investigate the sensitivity of both vertical and horizontal displacements to the chosen reservoir model.

G31C-0166 0830h POSTER

Monitoring Undersea Crustal Deformation of the South Flank of Kilauea Volcano, Hawaii

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The south flank of Kilauea Volcano on the island of Hawaii undergoes large-scale deformation as a result of volcanic and tectonic processes. Most of the surface of Kilauea Volcano is submerged so that undersea monitoring of crustal deformation is needed to provide a complete model of its structure and dynamics. In November of 2000, an array of eight acoustic transponders and six seafloor benchmarks were installed offshore on the south flank of Kilauea. During a three-year study, this array will monitor horizontal deformation at six sites with centimeter accuracy by combining GPS and acoustic techniques. Vertical deformation will be monitored at fourteen sites to decimeter accuracy by combining pressure and CTD data. Multi-beam sonar mapping and near bottom side-scan sonar data were also collected to place the seafloor geodetic array in a geologic context. The overall goal of this project is to combine offshore and subaerial geologic and geodetic data to generate an improved model for the deformation and dynamics of Kilauea Volcano.

G31C-0167 0830h POSTER

Crustal Deformation Associated With the 2000 Eruption and Degassing Process of Miyakejima, Izu Islands, Japan

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Miyakejima is located in the northern part of the Izu Islands lying along the boundary between the Pacific plate and the Philippine Sea plate. Miyakejima volcano erupted on Miyakejima is located in the northern part of the Izu Islands which are a chain of volcanoes lying along the boundary between the Pacific plate and the Philippine Sea plate. Miyakejima volcano erupted on June 27, 2000 after the quiescence of 17 years. First eruption is a small submarine eruption 1.5km off the western coast of Miyakejima. Subsequently, several summit eruptions as tephra ejecta occurred in July and August 2000. The summit collapsed just after the first summit eruption and a caldera was formed for 40 days. Collapsed volume and erupted volume are estimated to be 0.6km^3 and 0.02km^3, respectively. In September 2000, the collapse caldera started emitting a large amount of volcanic gasses. A peak amount of degassing SO_2 is ~70000 ton/day in the period from October to December 2000. Amount of volcanic gas is decreasing gradually and is 15000 ton/day (SO_2) now. However, it is still larger than other active volcanoes.

Permanent GPS data reveals the spatial pattern and time evolution of ground deformation. Inflation of Miyakejima was observed by continuous GPS and leveling before the 2000 eruption. The observed displacements associated with the 2000 eruption show radial pattern suggesting shrinking of the island and subsidence. This pattern continues for 14 months from July 2000. Though the rate of crustal deformation is almost constant from July to August 2000, it is decreasing exponentially with a time constant of ~150days from September 2000.

We assumed a point deflation source and inverted the observed displacement to estimate parameters of the point source. Volume decrease and depth of the deflation source is 0.12km^3 and 4.2km from July to August 2000. We interpret that it is the squeezing of magma from a magma chamber of Miyakejima volcano. The displacement observed in neighbor islands suggests that the squeezed magma and collapsed material of Miyakejima migrated northwestward by as much as 30km in the form of a dike intrusion. Volume decrease and depth of the deflation source is 2.9km and 0.016km^3 from September 2000 to May 2001.

Decreasing rate of the deflation source is an order of magnitude smaller than that of the previous period. We considered that degassing from magma mainly causes the deflation of magma chamber after September 2000. The decreasing rate estimated from crustal deformation was quantitatively consistent with that estimated from the rate of the emitting volcanic gasses (Kazahaya, personal communication). This consideration suggests that the magma does not migrate any more and that the magma chamber is in closed system. However, recent rate of the deformation is much smaller than that calculated from the degassing rate. This implies that new magma is supplied to the magma chamber from deeper region or that the depth of magma head becomes deeper in a conduit from the magma chamber to the caldera.

G31C-0168 0830h POSTER

Seafloor Geodetic Observations West off Miyake-jima Island During January to April, 2001

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An intensive earthquake swarm started under Miyake-jima Island, 180km south off Honshu, Japan, on June 26, 2000. The earthquake swarm migrated towards northwest off from Miyake-jima Island, where numerous earthquakes, more than 100,000, were detected within about two months and an extensive crustal deformation was observed by on-land geodetic observations. We started seafloor geodetic observation in this area to monitor seafloor deformation for the better understandings of underground magmatic activities. This poster presents summary of the observations and preliminary results from them.

IIS has been developing a method of seafloor geodesy in corporation with JHD. A combination of kinematic GPS measurements and precise acoustic ranging techniques is employed to achieve centimeter-level seafloor geodesy. First observation site using the method was Kumano trough, where the Philippine Sea Plate subducts beneath Japan Islands arc. It was confirmed that the method could locate horizontal position of the seafloor reference points within 4 cm standard deviation (Asada and Yabuki, 2001). We apply this seafloor positioning method to the observations conducted in the area west off Miyake-jima Island.

Three seafloor reference systems (Stations A, B, and C), which consist of three or four acoustic mirror transponders, were built in triangle area surrounded by three islands, Miyake-jima, Nii-jima and Kouduj-jima Islands, in November and December, 2000. This area would be deformed remarkably due to underground magma movement including magma injections from deeper part. Distances among three reference systems were set about 15 km. Stations A and B were located on the two sides of NW-SE trending seismically active area. The observations have been conducted three times until present, in January, February and April 2001. We obtained less data than we had expected due to bad sea condition in January and February observations. Also, a fast and quickly varying ocean current prevented us from keeping ship lines as they were planned at the observation in April. Although the amount and quality of the data might be less and worse than projected, analyses are going on by improving software suitable for each data set in order to extract as much information as possible from available data.

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Magma transfer processes at persistently active volcanoes

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A persistently active volcano is one that releases significant amounts of volatiles and heat energy over hundreds to thousands of years. An essential characteristic of persistently active volcanoes, whether they support a lava lake, an aqueous crater lake, fumaroles, or some combination of these, is that the surface activity is typically maintained at low mass flux levels for long periods of time. Several models have been developed from thermodynamical calculations and laboratory experiments to explain the mechanisms by which energy and gas can be transported to the summit of a volcano for extended periods of time. The key factor is that the system does not stagnate and cease to be active. Models invoke a process of convective overturn, which is that relatively gas-rich magma rises up buoyantly through a conduit system, degassing as it rises, the gas escaping either into the atmosphere directly, or into an overlying hydrothermal system. The degassed magma then becomes denser due to the loss of volatiles and decrease in temperature and descends to a depth where it accumulates. It has been shown to be theoretically possible to maintain a thin pathway of magma open for extended periods of time in such a conduit. The processes of convective overturn within a conduit feeder system and magma accumulation at depth will occur on different time scales. Short timescale (seconds-years) magma movements within shallow conduit systems have been directly detected using geophysical methods, however, the longer-term processes of accumulation of magma have never been directly detected.

Here we show how repeat micro-gravity measurements are capable of discriminating mass changes associated with both the shallow and deep processes predicted to be occurring at persistently active volcanoes. We present new data from Poas volcano, Costa Rica illustrating how shallow magma can be tracked with considerable detail.