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Kilauea Volcano Provides Hot Seismic Data for Joint Japanese-U.S. Experiment

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A team of 25 researchers from the United States, Japan, and Italy joined the staff of the Hawaiian Volcano Observatory (HVO) from January 8 through February 9, 1996, to make the most detailed seismic recordings on Kilauea Volcano ever. One-hundred-sixteen portable seismographs were installed in and near Kilauea Crater in Hawaii Volcanoes National Park as a joint Japanese-U.S. research project to record volcanic earthquakes and tremor. The importance of these events has long been recognized, but their origin remains poorly understood due to inadequate network coverage and limitations of the analog instrumentation used in the past.

On February 1, a swarm of over 500 earthquakes was recorded by the dense network, providing the best recording of an intrusive earthquake swarm at Kilauea. The data collected offer an unprecedented opportunity to understand earthquakes associated with magma transport.

Experiment

This project was begun under a Japan-U.S. Science and Technology (JUST) agreement for natural hazards reduction and mitigation. A JUST working group on volcano seismology selected Kilauea Volcano, Hawaii, as a study site, since its ongoing eruption provides a unique opportunity for a large-scale seismic monitoring effort.

Three dense arrays of seismographs were deployed (Figure 1) to record earthquakes and tremor activity originating beneath Kilauea's summit caldera. The first array was a 300-m aperture antenna consisting of 31 three-component sensors (Figure 2). The arc spacing of 50 m and sensor interval were selected to assure optimum sampling of signals for frequency-slowness studies [*Goldstein and Chouet, 1994*] and for investigations of the polarization and phase velocities of the wave fields using the stochastic wave method [Aki, 1957, 1965; *Ferrazini et al.*, 1991]. Similar antennas have been deployed at other volcanic sites in the past [*Dietel et al.*, 1989, 1994].

The second Kilauea array consisted of two concentric rings with diameters of 2 and 4 km, respectively, surrounding a central receiver (Figure 1). This configuration provided excellent azimuthal coverage for events occurring beneath Halemaumau Crater near the center of the array. A similar experiment in the near field surrounding the Izu-Oshima crater revealed that the tremor

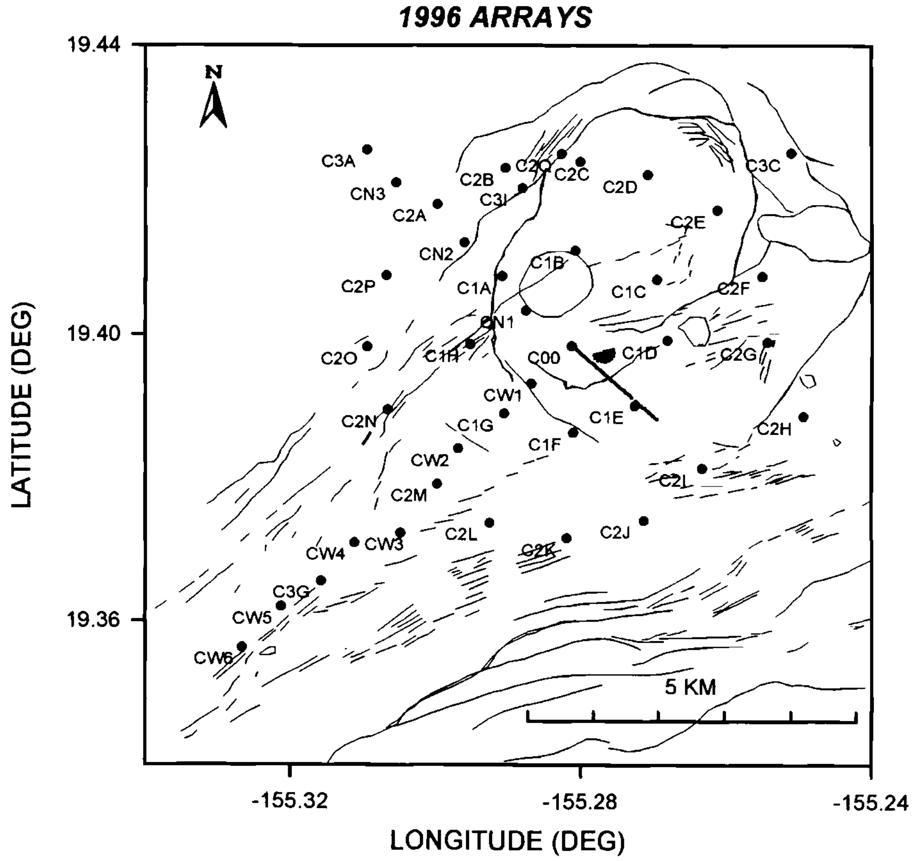

Fig. 1. Map of the entire January 1996 portable seismic network, including outlines of Kilauea caldera and Halemaumau crater, and positions of major faults. Each dot marks the position of a seismic station; clusters of small dots mark two dense subarrays. The A1 antenna is just to the left of the label for station C1D, and the B linear array (indicated by line) extends from station C00 to the southeast through C1E. "1996 Arrays" refers to the instrument configurations in 1996.

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A1 ANTENNA and B - LINE

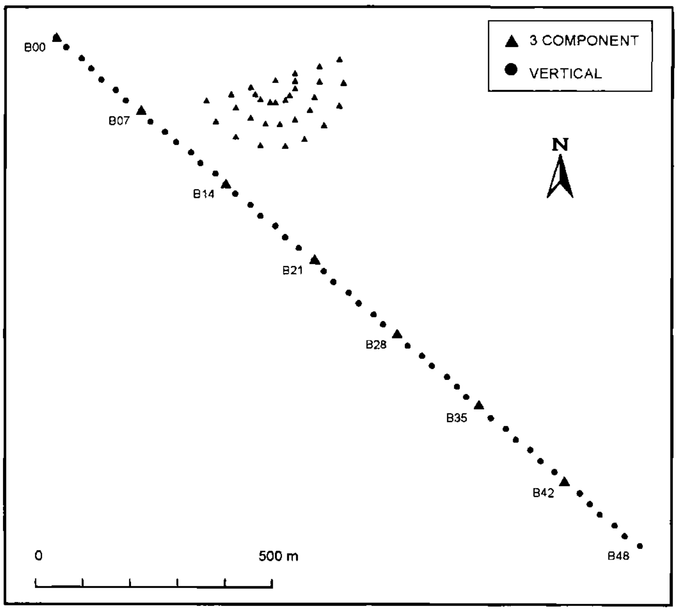

Fig. 2. Map of the A1 antenna and B-line. All the sensors in the A1 antenna were three-component instruments. The B-line consisted of both single-component vertical sensors (circles) and three-component (triangles) sensors. Selected station names are indicated for the B-line.

was composed of the type of isotropic waves that would be expected from volumetric vibration at the source [*Yamaoka et al.* 1991]. The third array consisted of 48 sensors along a line oriented south-southeast from the center of the circular network (Figure 2). The receiver spacing of 35 m ensured wave coherence between adjacent stations. This dense linear array was deployed to study wave transmission as a function of distance. A similar dense array was deployed at Izu-Oshima to determine the source time function of volcanic tremor [*Oikawa et al.*, 1994]. Additional receivers were added to the southwest and northwest arms of the circular arrays to improve station density. Receiver positions were determined by the Global Positioning System for the entire network.

The equipment installed on Kilauea included portable, digital data loggers that recorded up to three seismic data channels with a Global Positioning System time signal. Power was supplied by a rechargeable battery. Up to 20 MB of data were recorded in the data logger flash memory and then downloaded into notebook computers during site visits. Data were then downloaded from the notebook computers into a workstation at HVO. The data loggers were run in continuous mode from January 11 through January 21, and in event-triggered mode thereafter.

The network of seismometers and portable data loggers was nested within the network of permanent seismic stations that transmit their signals via FM radio for recording and analysis at HVO. Over the past few years, HVO has upgraded its instrumentation and data transmission and acquisition schemes, and in 1993 a network of 10 digitally telemetered, three-component broadband seismometers was installed in the summit region. With the 123 channels of seismic data presently transmitted to HVO, the data loggers brought the total number of seismic data channels recorded on Kilauea in January 1996 to 389 when all the loggers were operating. Over 40 GB of data were collected during the month-long experiment.

Data and Analysis

The principal goal of the experiment was to record volcanic tremor and volcanic earthquakes. Such signals are especially common at active volcanoes and have been documented at over 160 volcanoes worldwide [*McNutt*, 1994]. The tremor signal during most of the recording period was weak, associated with the steady, effusive lava flow from the Pu'u O'o eruption site in the Kilauea east rift zone. Shallow, long-period earthquakes beneath Kilauea caldera were recorded by the portable network.

Twenty-five of the portable digital stations were still operating when over 500 earthquakes were recorded at Kilauea crater from 0800–1300 HST on February 1. It is likely that the portable units recorded many earthquakes that were too small to process through the routine HVO data analysis procedures. The denser network, which consisted of both the telemetered digital stations and the portable data loggers complementing the HVO analog array, made the February 1 intrusive earthquake swarm the best ever recorded at Kilauea. The additional bandwidth and dynamic range afforded by the digital field equipment offer a unique opportunity to analyze earthquakes associated with magma migration and eruption.

Hundreds of volcano-tectonic earthquakes were also detected by the HVO network during the course of the experiment, including many earthquakes that occurred beneath other parts of Hawaii.

The working group will continue to investigate source processes and the nature of seismic wave propagation under Kilauea using a range of data analysis techniques. Researchers plan to determine precise event locations; perform frequency-slowness and correlation analyses of long-period events, tremor, and volcano-tectonic earthquakes; perform detailed source modeling; and develop fine-scale three-dimensional tomography using both P and S waves. Other objectives include performing studies of the site, propagation and topography effects; and investigating the heterogeneity and scattering properties of the volcanic medium using coda waves and teleseismic studies.

These data and analyses will provide the most definitive view to date of volcanic earthquakes and tremor, and will serve as a benchmark for future studies. While there are already many tools available for data analyses, this unprecedented collection of data will allow us to capitalize on new procedures developed in the future. Besides studying the data collected in this January 1996 experiment, the working group is planning another seismic survey in Hawaii for early 1997, probably near Pu'u O'o. This will be followed by a similar survey at another volcano—hopefully an explosive one—in the United States, Japan, or another country the following year. Detailed seismologic investigations on volcanoes can greatly improve our understanding of how volcanoes work and how volcanic disasters might be averted through monitoring.

Preliminary results of data analyses were presented at a special session of the 1997 meeting of the International Association of Volcanology and Chemistry of the Earth's Interior in Puerto Vallarta, Mexico. Representative seismograms, detailed maps, site descriptions, and results of initial data analyses will be included in a U.S. Geological Survey Open-File Report or *Bulletin of the Earthquake Research Institute*, University of Tokyo. In addition, a special issue of the *Journal of Volcanology and Geothermal Research* dedicated to results from this experiment is being planned.

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23 Science Societies Issue Joint Call for More Federal Research Dollars

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In an unprecedented demonstration of unity, the leaders of 23 American scientific societies and umbrella organizations gathered on March 4 in Washington, D.C., to press the U.S. federal government for increased funding for scientific research and to make an investment in the nation's future. In a "Joint Statement on Scientific Research" addressed to President Bill Clinton and the Congress, the presidents of learned societies representing more than one million scientists, mathematicians, and engineers asked the government "to renew the nation's historical commitment to scientific research and education," and to reverse the decline of federal investment in science and engineering. The American Geophysical Union was one of the signatories of the statement.

"We strongly believe that for our nation to meet the challenges of the next century, agencies charged with carrying out scientific research and education require increases in their respective research budgets in the range of 7% for fiscal year 1998," the coalition of scientific societies said in its statement. "Those agencies include, among others, the National Science Foundation, the National Institutes of Health, the Department of Energy, the Department of Defense, and the National Aeronautics and Space Administration." The 7% increase would "partially restore the inflationary losses that most of the agencies suffered during the last few years," the coalition noted (see Figure 1).

By joining forces to make the statement, scientists and disciplines that have competed with each other in the past for federal dollars are now standing together in an interdisciplinary union. "The fields of science have become so interdependent in recent years that advances in any one field are critically dependent upon breakthroughs in other fields—frequently in fields that might seem completely unrelated," said Allan Bromley, president of the American Physical Society and former science advisor to President George Bush. "In consequence, cuts in the support and level of activity in any one area are soon felt throughout the entire research enterprise."

"What is remarkable about the joint statement is not the statement itself, but that 23 scientific societies have agreed for the first time to speak with one voice," said AGU President Sean Solomon, who signed the statement on behalf of the Union. "The coordination of public policy messages among representatives of the physical sciences is long overdue."

The announcement of the Joint Statement on Scientific Research was generally well-received by members of Congress, although some members see the request as wishful thinking, given the current budgetary climate in the United States.

The new chairman of the House Science Committee, Representative James Sensenbrenner (R-Wis.), noted in a March 4 interview on C-SPAN that "increased spending on R&D pays dividends for all of us." But he cautioned that while the leaders of the scientific societies are "well-intentioned," the major problem facing the country right now is the federal budget deficit. If the Congress and the Executive Branch can agree on a formula to balance the budget, Sensenbrenner said, "I would hope that science is one of our top priorities."

Rep. George Brown (D-Calif.), ranking minority member of the House Science Committee, added that "while there are several proposals and requests to increase spending on research, none of those proposals identifies how such increases will be accommodated in a balanced budget scenario. Until you take that step, you are just playing with Monopoly money," he said. Brown also an-

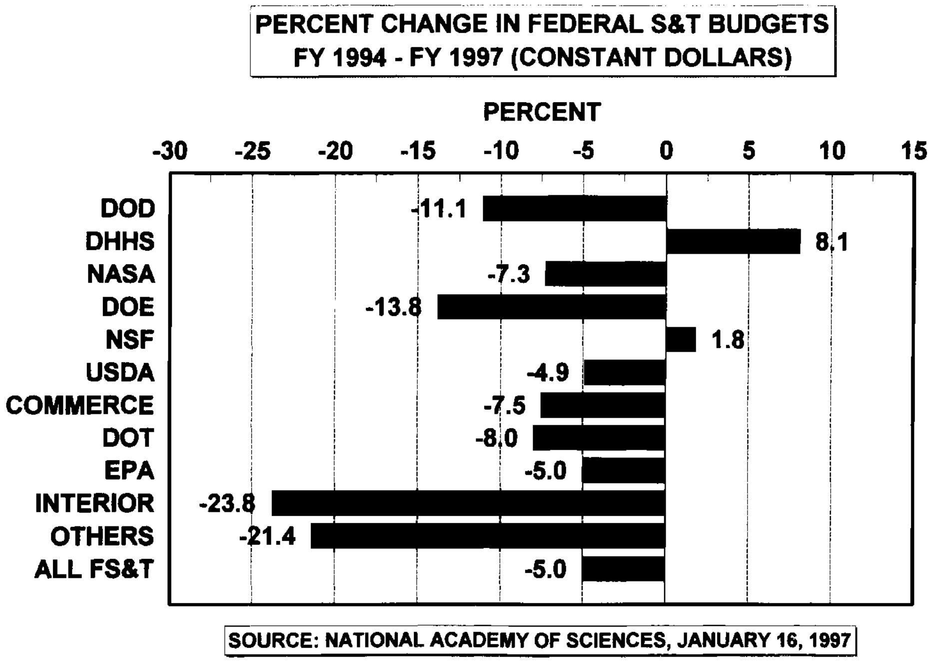

Fig. 1. When adjusted for inflation, the science and technology budgets of most federal agencies have declined steadily since 1994, following nearly four decades of growth.