Paper G 7

A NEW METHOD FOR MONITORING GLOBAL VOLCANIC ACTIVITY

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The ERTS Data Collection System makes it feasible for the first time to monitor the level of activity at widely separated volcanoes and to relay these data rapidly to one central office for analysis. This capability opens a new era in volcanology in which the hundreds of normally quiescent but potentially dangerous volcanoes near populated regions around the world can be economically and reliably monitored daily to warn when any one volcano is becoming active again. Before ERTS was launched, only a few volcanoes in the world were monitored continuously because of the high cost of building and staffing volcano observatories. Yet it is known from data collected in this century that while visible signs of pending eruptions may only occur minutes to days in advance, invisible but measureable signs may be detected days, weeks, months, and even years before a major eruption. While prediction of specific eruptions is still an evasive goal, early warning of a reawakening of quiescent volcanoes is now a distinct possibility.

A prototypical global volcano surveillance system was established under the ERTS program during the past year. Instruments were installed in cooperation with local scientists on 15 volcanoes in Alaska, Hawaii, Washington, California, Iceland, Guatemala, El Salvador and Nicaragua at the sites shown in Figure 1. Data from low-powered instruments in each of these many remote locations are being relayed six to ten times daily through the satellite to the ground tracking stations at Goldstone, California, and Goddard Spaceflight Center in Maryland. The data are processed at Goddard and then relayed within 90 minutes by teletype to the National Center for Earthquake Research in Menlo Park, California.

The sensors include 19 seismic event counters that count four different sizes of earthquakes and six biaxial borehole tiltmeters that measure ground tilt with a resolution of 1 microradian. Only seismic and tilt data are collected because these have been shown in the past to indicate most reliably the level of volcano activity at many different volcanoes. Furthermore, these parameters can be measured relatively easily with new instrumentation. The fourth-generation seismic event counter developed for this project is shown in Figure 2. This instrument compresses seismic data gathered at the rate of about 2 million digital bits per 12 hours to a small number of bits such as 64 that can be economically relayed through a satellite. This compression is not easy, and some data are lost. For the purposes of this project, however, the main data desired are simply the number of events of different sizes. These numbers typically change by orders of magnitude before eruptions. The criteria adopted for detecting events are that 10 peaks of the full-wave rectified seismic signal must be above a given threshhold in 1.2 seconds and that there must have been no peak above this threshhold in the previous 15 seconds. The second criterion effectively inhibits the counter during periods of high ground noise caused by wind, harmonic tremor, people, and so on. The time that a channel is inhibited is counted separately and indicates the relative level of ground noise. The number of earthquakes greater than four different amplitudes and the noise counts for each channel are relayed through the satellite. Each counter contains 120 COSMOS integrated circuits and has proven quite reliable. In fact the counters are significantly more reliable than the transmitters furnished by NASA, which use one-third as many integrated circuits but fail quite often.

The transmitter, event counter, seismic sensor, and batteries used for one year's operation are shown in Figure 3. The portability and low power consumption of these instruments makes them practical for operation in remote locations in all types of environments.

A typical installation on the Volcan San Cristobal in Nicaragua is shown in Figure 4. The equipment is locked in steel boxes cemented in place. The antenna is mounted about 12 feet off the ground with a plexiglass dome protecting the elements. A standard seismometer with VHF radio telemetry to some nearby recording site is also installed next to most event counters in this initial program to show whether the event counters are compressing the seismic data reliably. There has only been one minor case of vandalism so far. A few stations have been damaged by lightning.

The tiltmeter used in this project is shown in Figure 5. The bottom of the pipe, which is about 5 cm (2 in) in diameter, contains a precise electrically monitored level bubble that has been adapted for this use from a defense application. The pipe is placed in a 4-to-10-foot hole in rock or more typically sandy soil or ash. The output of the electronic equipment shown connects directly to the satellite transmitter. These instruments have worked very reliably except for some lightning damage that should be avoided in the future with some new design changes.

A sample of the tiltmeter data from Hawaii where three meters are set up several kilometers apart around the central caldera of Kilauea volcano is given in Figure 6. The graph in the upper left shows a comparison over several months of the output of one of these meters compared with the outputs of a mercury tube and a water tube tiltmeter that have operated in the same location for many years. This comparison is exceptionally good for tilt data. The scatter for the water tube meter is noise that represents the limit of resolution for the instrument.

The upper right-hand plot shows the tilt at one of these instruments for 5 months in early 1973 with a tilt event on May 5th. The lower plots show the same tilt event in detail as recorded by the three meters. The three tilt vectors show that the summit of the volcano subsided causing tilts on the order of 10 to 30 microradians or 10 to 30 mm of subsidence in 1 km. An eruption of lava from the flank of Kilauea closely followed this deflation. At present Pacaya volcano in Guatemala is inflating at about 150 microradians per month, and a second tiltmeter was just installed to monitor this event more closely. Pacaya has had minor eruptions continuously for several years.

The number of earthquakes counted by an event counter on Mt. St. Helens in Washington is compared with those counted by a seismologist on standard instruments located next to the counter in Figure 7. Generally, we find that the counters accurately show the level of seismic activity. There is not a one to one correspondence between counts and earthquakes and this is not surprising since two seismologists might not agree on the exact number of earthquakes. The counts, however, do approximate the number of earthquakes except during periods of high noise that can be identified by the separate inhibit-time or noise counters.

The events of two different sizes counted on the volcano Fuego in Guatemala that erupted beginning on February 22, 1973 show an increase in activity during an eruption (Figure 8). The counter was installed in February. Note the significant increase in activity about 5 days before this small eruption began. The seismic activity was high during the eruption and returned to a low level after the eruption was over. A different counter 30 km from Fuego showed no change in seismic activity during the whole period. This implies the seismic activity was indeed at Fuego. The noise counts were high during periods of high harmonic ground tremor probably associated with the movement of lava underground.

Spurious event counts are usually flagged by the presence of significant noise counts. A second necessary criterion is also clearly shown here. The peak of events on March 18 on the high-gain channel is not observed on the low-gain channel. Since a large number of small earthquakes will always be accompanied by a few larger earthquakes, according to a well-established logarithmic relationship, we can infer that this peak is caused by spurious noise. In this case the spurious counts are caused by moderate harmonic tremor.

These event count data show the types of changes anticipated before destructive eruptions. More gradual changes should also be noted as the period of recording increases.

In conclusion a prototype global volcano surveillance system has been developed under the ERTS program with instruments on 15 volcanoes, in five countries. The instruments are working reliably and some data of the type anticipated have been collected. This work clearly demonstrates the technological feasibility of a global surveillance system although many details in the design of highly reliable instruments still need to be worked out. The primary effort in the future, however, needs to be the collection and analysis of data from these different volcanoes to establish clearly the scientific feasibility of this novel and potentially revolutionary approach to surveillance of hazardous volcanoes.

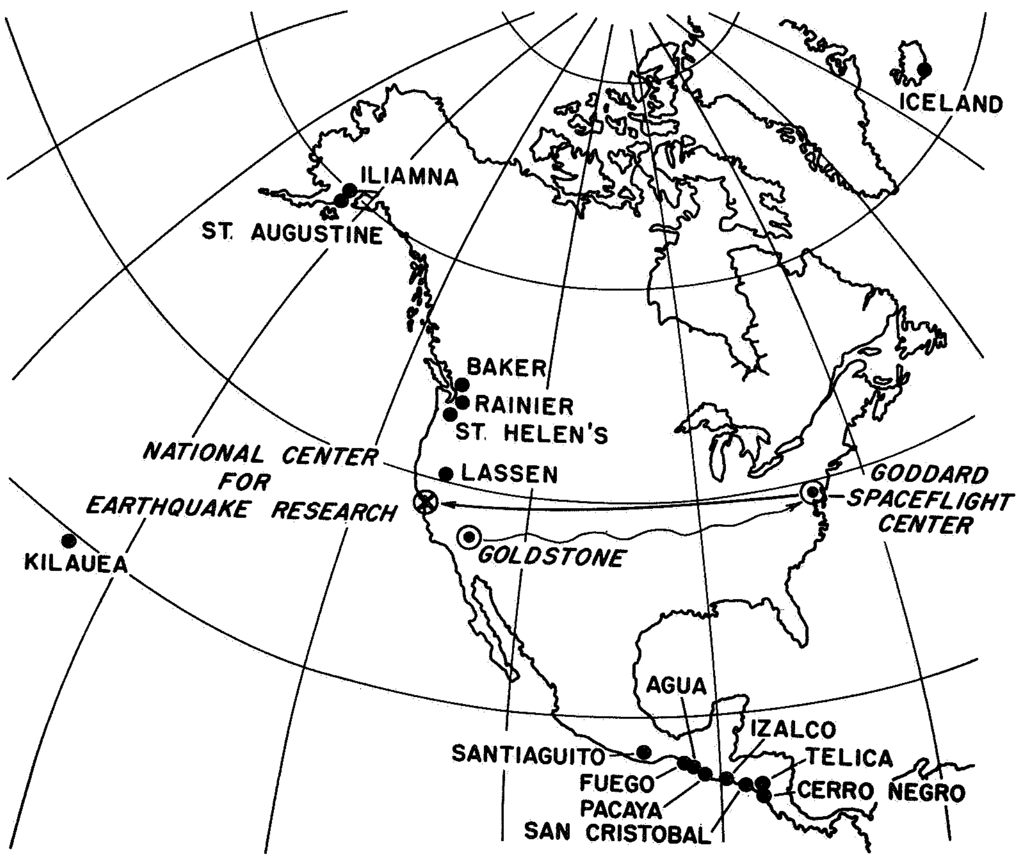

Figure 1: Map of volcanoes monitored in this study. Event counters are placed at all sites. Tiltmeters are placed on Mt. Lassen, Kilauea, Fuego, and Pacaya.

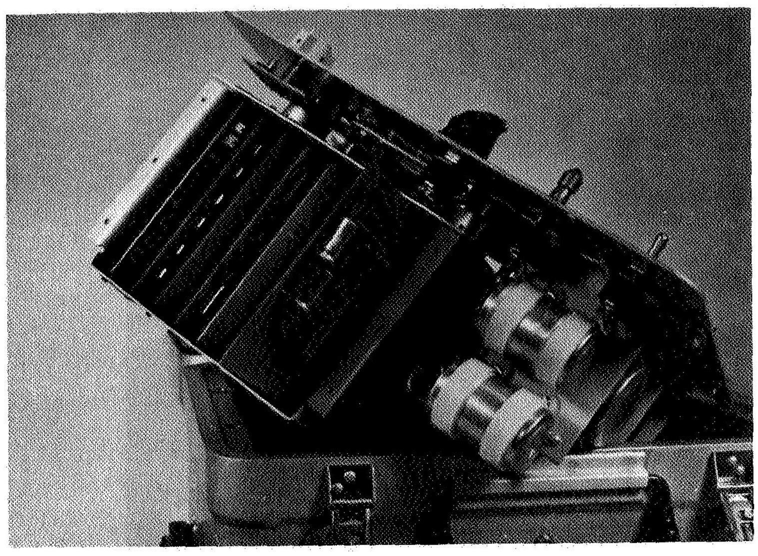

Figure 2: View of the inside of the seismic event counter showing some of the 8 circuit cards.

Figure 3: Satellite transmitter (left), seismic sensor (left foreground), seismic event counter (center), and batteries (right) used to monitor seismic activity and send the data to the satellite.

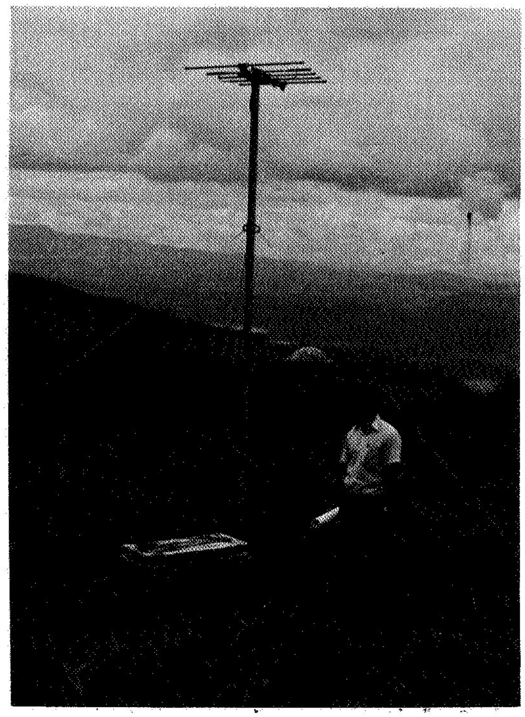

Figure 4: Installation of the standard seismometer (foreground) and seismic event counter system (background) on Volcan San Cristobal in Nicaragua.

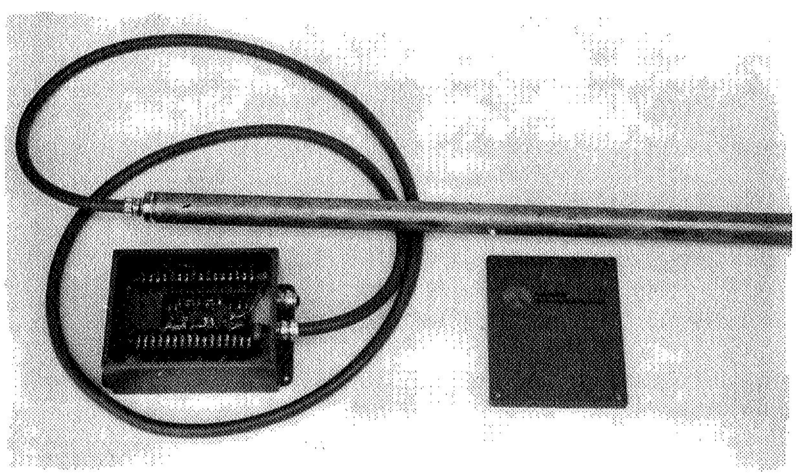

Figure 5: Biaxial tiltmeter and electronics used in this study. The tube is about 5 cm (2 in) in diameter and about 1.3 m (48 in) long.

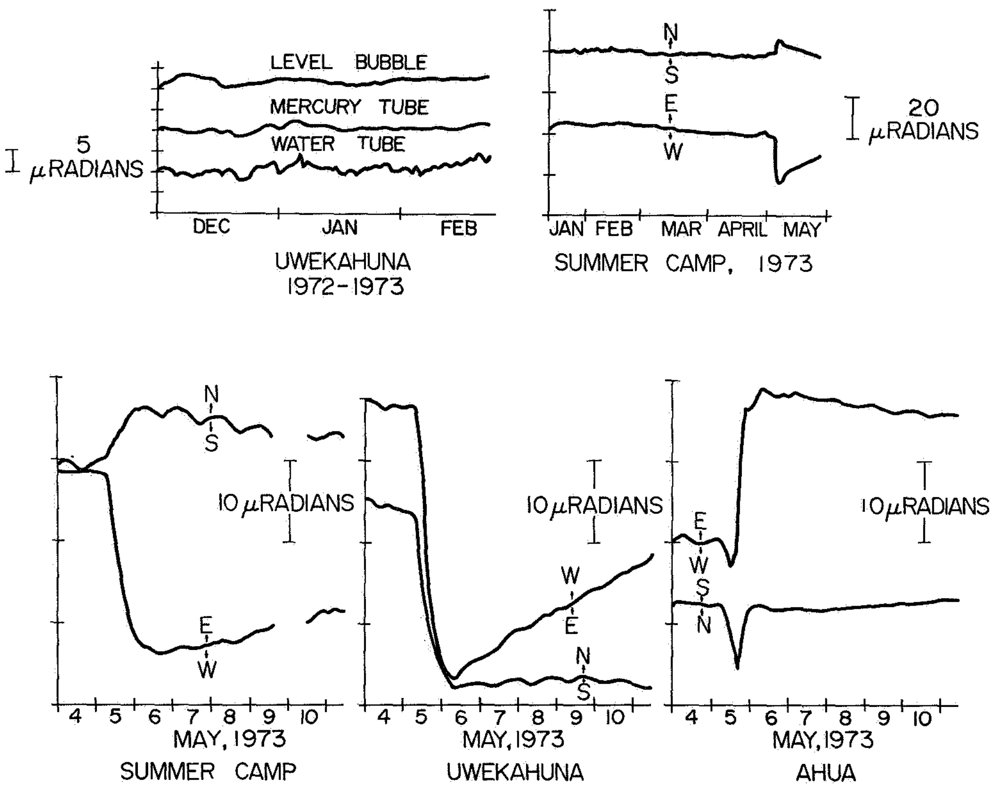

Figure 6: Typical data from three tiltmeters located around the central caldera of Kilauea Volcano during a collapse of the caldera area. The data in the upper left shows a comparison of the new level bubble tiltmeter with two other types of tiltmeters operated in Hawaii for several years.

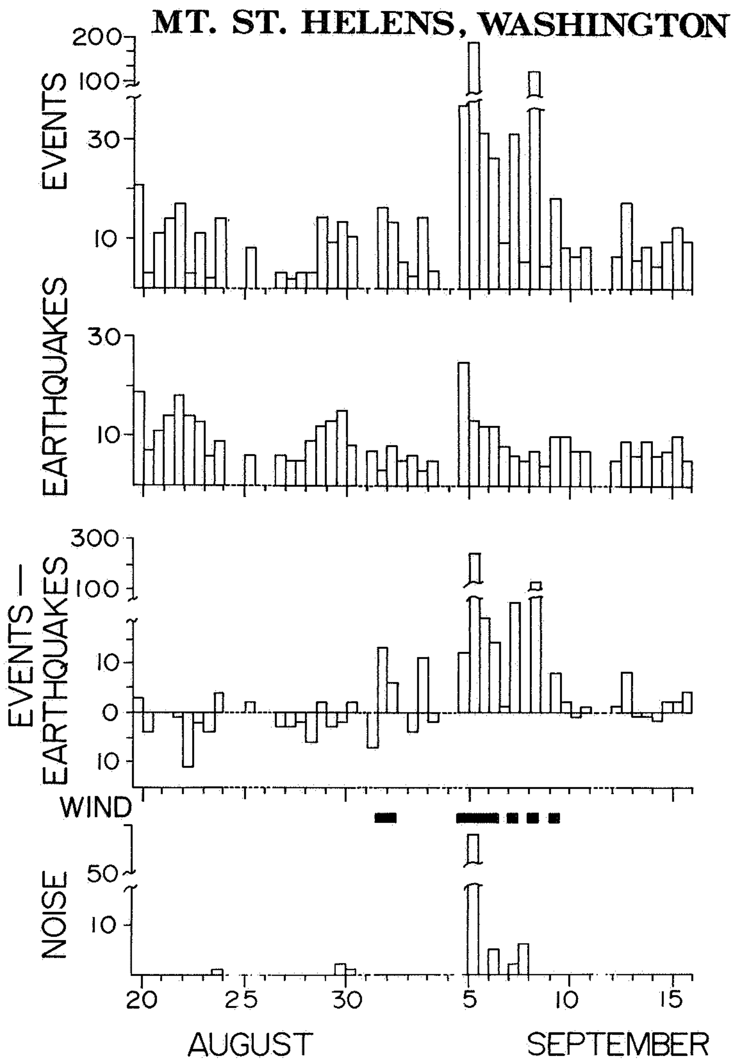

Figure 7: Seismic events counted by the event counter on Mt. St. Helens in Washington compared to earthquakes detected by a seismologist from a seismograph operated nearby.

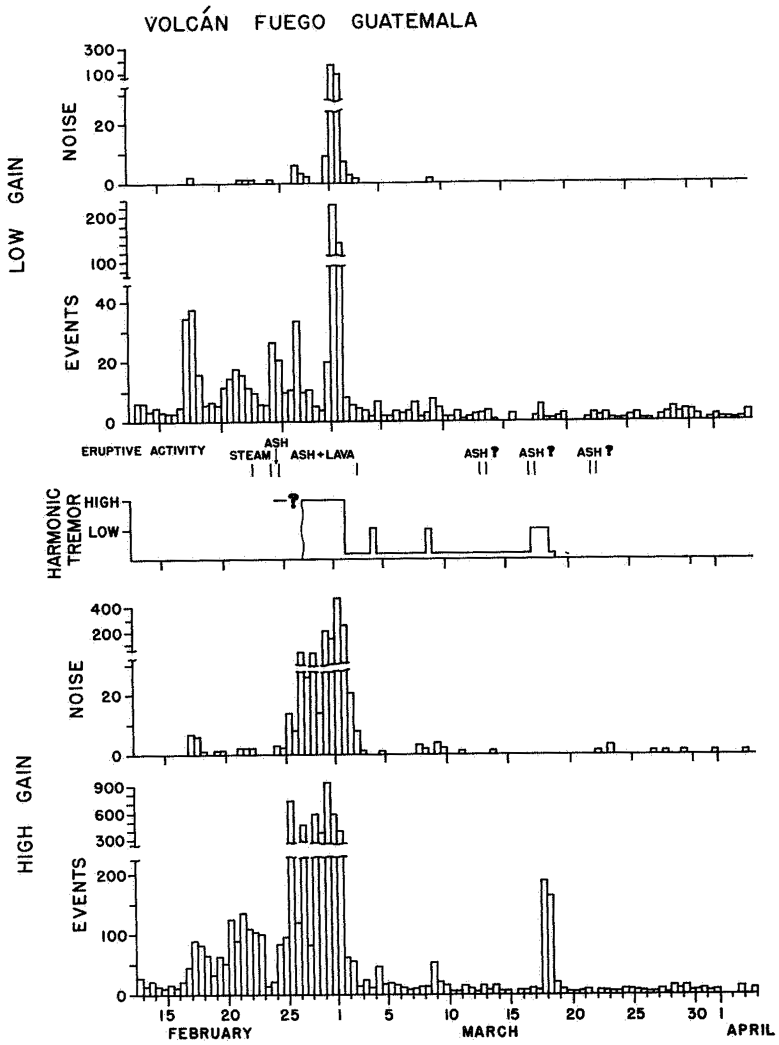

Figure 8: Seismic events and noise counted near Volcan Fuego in Guatemala in early 1973. Note the increase in seismic activity during during the eruption in February.