The second most important mechanism is precipitation and coprecipitation of the metals in the metallic coating on the particles. For Fe, Mn, and Ni this is the major mechanism of transport, and for Co it is second most important. It is probable that the Ni, Co, and Mn are coprecipitated with the much larger amounts of Fe found in the coatings.

Transportation of trace metals in solution accounts for a significant percentage (up to 17 percent) of the total carried only in the case of Mn. Theoretically, the stable form of Mn in the normal oxidizing conditions and *p*H (5 to 7) of the rivers is solid MnO_2 and should not be the soluble form, Mn^{2+} (*8*). It is possible that the Mn analyzed in solution may have been in very small solid particles; however, this is unlikely since filtering water through 0.1-μm filters resulted in the same retention and concentration of Mn as filtering it through 0.45-μm filters. Also, it would seem fortuitous that only the Mn was fine enough to pass through the filters while none of the other five trace metals did. Other possibilities are that the Mn was complexed with organic molecules or was associated with inorganic molecules.

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4. After the filtration at 0.45 μm, several samples from each river were filtered at 0.1 μm in order to determine whether any finer material was passing through the coarser filter. The first 10 percent of the water sample was filtered before a portion was taken for analysis. By this procedure the filtering device and filter were washed and the filter became partially clogged, materially reducing the effective pore size. The analytical results on the filtered water showed no significant difference between water filtered with 0.1-μm pore size and water filtered with 0.45-μm pore size.
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Kilauea Volcano, Hawaii: A Search for the Volcanomagnetic Effect

Abstract. *Brief excursions of magnetic field differences between a base station and two satellite station magnetometers show only slight correlation with ground tilt at Kilauea Volcano. This result suggests that only transient, localized stresses occur during prolonged periods of deformation and that the volcano can support no large-scale pattern of shear stresses.*

For many years investigators, particularly in Japan, have surmised the existence of a volcanomagnetic effect in the form of transient magnetic anomalies associated with eruptions (*1*). Measurements made with a pair of interconnected proton magnetometers on Ruapehu and Ngauruhoe volcanoes in New Zealand (*2*) encouraged the hope that magnetometry might provide a tool for predicting eruptions. Kilauea Volcano, Hawaii, appeared to offer a particularly favorable area for observations of this kind because of its frequent eruptions, the highly magnetic, basaltic rocks found in the area, and the proximity of the Hawaiian Volcano Observatory as a logistic basis for the operation of an instrumental array. We therefore planned a collaborative program using a network of three total-field magnetometers, with a base station linked by radio to two satellite stations. We now have 12 months of records, which, although broken, lead us to the tentative conclusion that stress-strain effects accompanying eruptions of Kilauea are different from those of the New Zealand volcanoes.

Except for a 3-month period, the base station sensor has been located at the Uwekahuna Vault, close to the observatory; during July through September 1971 it was at the Outlet Vault, which was engulfed by lava during the

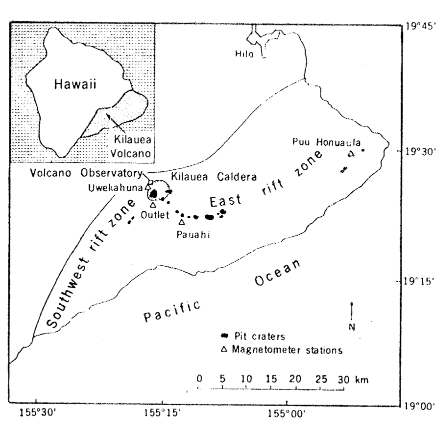

Fig. 1. Location map showing major structural and eruptive features of Kilauea Volcano with sites of the magnetometer sensors.

September 1971 eruption. The satellite sensors are located near Pauahi Crater and Puu Honuaula, 10 and 43 km, respectively, along Kilauea's east rift zone from Uwekahuna (Fig. 1). The total field at the base station is recorded every minute, and differences in field strength between the base station and each satellite are recorded on alternate minutes. The difference field readings are obtained by applying a 1-Mhz signal to the "up" and "down" inputs of reversible counters, with inputs gated by 1024 cycles of the two simultaneous proton frequencies to be compared. The readings are obtained as printed paper tape for immediate examination and magnetic tape for computer processing. The instrumental resolution is 0.05 gamma, but trials with closely spaced sensors gave difference field readings having a standard deviation of 0.2 gamma, and this has been achieved also for hourly periods during magnetically quiet times over the Hawaii network. Although we discriminate against magnetic disturbances of remote origin by taking differences, because of the proximity of seawater in which electric currents are induced by geomagnetic variations, a diurnal variation of 10-gamma amplitude appears in the record of Puu Honuaula minus the base station but there is only a 1-gamma amplitude variation in the record of Pauahi minus the base station. However, the standard deviations of daily averages are less than 1 gamma in both cases.

A program of tilt and strain measurements on Kilauea is well developed (*3*) and shows pronounced inflation of the summit region before eruptions and deflation during flank eruptions. We supplemented the tiltmeter network by installing in the Outlet Vault a continuously recording mercury level tiltmeter (*4*), and a commercial instrument of the same design (*5*) was added by J. M. W. Rynn of the Lamont-Doherty Geological Observatory. Both tiltmeters were destroyed during the September 1971 eruption. The presumption upon which our experiment was based is that the strains indicated by the tiltmeter and Geodimeter measurements are at least partly elastic and therefore that the stresses cause an observable piezomagnetic effect in the strongly magnetic rocks of Kilauea.

Tilt of the order of 10^{-4} radian implies strain of the order of 10^{-4} and, if this is perfectly elastic, the corresponding stress in basalt (rigidity, 3×10^{5} bars) would be 30 bars. The magnetizations of Hawaiian lavas are dominated by remanence, which is normally 5×10^{-3} electromagnetic unit or more (*6*), which we therefore use as a conservative estimate. Curie points indicate titanomagnetites of composition such that we can assume a stress sensitivity of magnetization of 2×10^{-4} bar^{-1} (that is, a change of magnetization by 2 parts in 10^{4} parts per bar of stress) (*7*). These figures give a change in magnetization of not less than 3×10^{-5} electromagnetic unit and a consequent magnetic anomaly of the order of 10 gammas (*8*) if the rocks are magnetic to a substantial depth.

Our supposition that the development of a magnetic anomaly would correspond directly to tilt records was not confirmed by the observations. A slight trend is apparent in some of the data, and striking, but brief excursions of magnetic field differences have been observed on several occasions but these are not clearly correlated with features of the tilt records. Examples of these excursions are compared with the tilt data in Fig. 2, in which it appears that there may be an association of the magnetic anomalies with irregularities of the tilt records. However, the effect is highly localized. The base station sensor was located at the Outlet Vault during the period from July through September 1971 with the expectation that a stronger effect would be apparent nearer to the source of deformation, but, as shown in Fig. 3, no magnetic anomalies developed at this site, even during a period of violent tilting.

The simplest explanation of our observations is that only transient, localized stresses occur during prolonged deformation of Kilauea Volcano. The absence of a prolonged piezomagnetic anomaly cannot be due to the fact that all of our sensors are located at nodes in the anomaly pattern, because the center of volcanic inflation has shifted during the period of our observations. Rather we suggest that the volcano can support no large-scale pattern of shear stresses. We can at present see no alternative to our tentative conclusion that only transient and highly localized stresses (accompanying local readjustments) occur during prolonged deformation of Kilauea Volcano. We are continuing the magnetic observations to test this conclusion under as wide a range of magnetic and eruptive conditions as possible.

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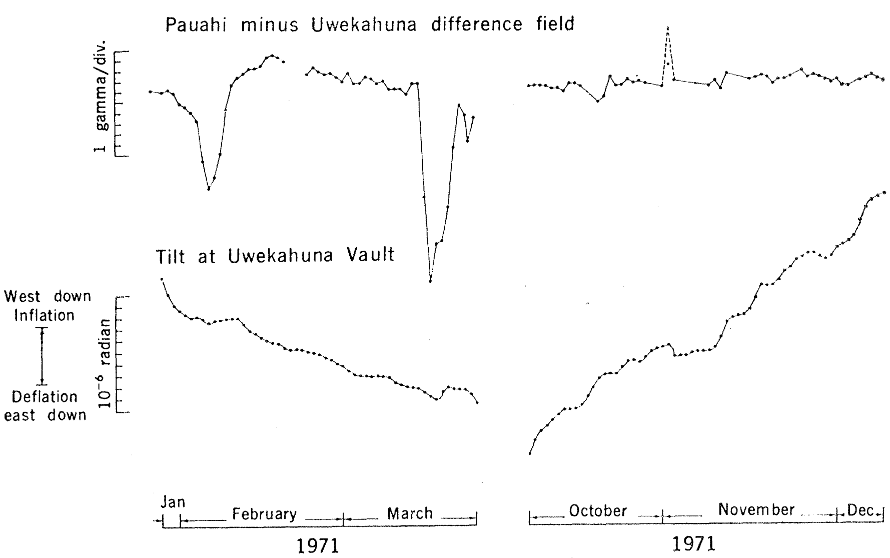

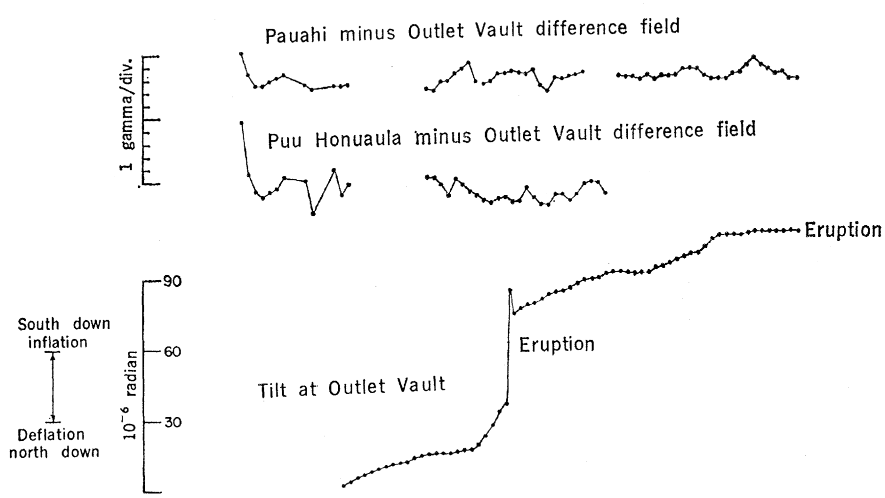

Fig. 2 (top). Magnetic difference field records (Pauahi minus Uwekahuna) during two periods of active tilting. Each magnetic data point is a 24-hour average of readings taken at 2-minute intervals. The broken line at 2 November indicates a striking anomaly of only a few hours' duration. Fig. 3 (bottom). Difference field and tilt records obtained with the magnetometer base station at the Outlet Vault, showing the absence of magnetic anomalies at this site, even during violent tilting.

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