# Electromagnetic mapping and modeling of active lava tubes on Kilauea Volcano, Hawaii


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## INTRODUCTION

The role of lava tubes in basaltic volcanic processes is significant; these subsurface conduits insulate extruding lava allowing it to flow great distances before solidifying. The low slope of shield volcanoes has been partially attributed to the ability of lava tubes to efficiently transport lava away from its source (Peterson and Holcombe, 1991). Lava tubes are prominent features on Kilauea Volcano; 58 percent of Kilauea's flows are tube fed (Greeley, 1978). This study focuses on a tube system formed by the progressive extension of a pahoehoe sheet flow. Pahoehoe sheet flows develop from lava flows which initially begin as thin sheet flows. When a thin pahoehoe sheet cools, it becomes strong enough to retain incoming lava beneath its surface, and inflates. The flow front is advanced by toes which break out of the newer, thin skinned flow front (Hon et. al., 1994). The molten core of the inflated sheet cools inward while tubes feeding the flow front develop. These tubes often fill in when their lava source is shut off (Hon et. al., 1994).

Lava tubes have complex morphologies; they have straight sections, meander loops, gentle curves, braided patterns, and distributaries (Greeley, 1978). The constantly changing morphology of lava tubes and the infrequent draining of tubes formed by extension of pahoehoe lobes make the study of active lava tubes necessary to understand this volcanic process. Electromagnetic instruments are invaluable tools in the study of active lava tubes (Zablocki, 1976). In this study an EM-31D non contacting terrain conductivity meter and a very low frequency receiver (VLF) were used to map and monitor changes over a section of lava tube. In late July and early August of 1996 a constant outpouring of lava occurred at the Pu'u O'o vent. This lava erupted directly into a tube flowing southeast towards the Pacific Ocean (Figure 1). This tube splits into two distributaries, and the largest of these distributaries flows South through a reoccupied tube system. The second distributary had a smaller lava influx, entered the ocean as several distributaries, lacked skylights, and had experienced recent surface lava breakouts. This distributary was the focus of this study and is known as the West Liapuki Tube System (Figure 1).

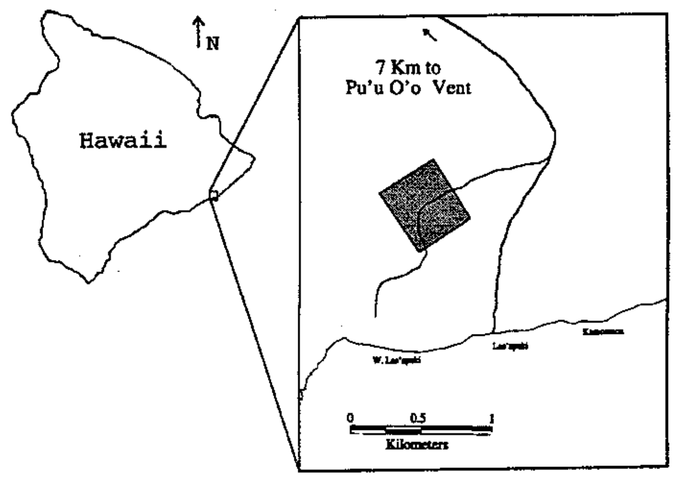


Figure 1: Map of Hawaii, lava tube system, and study area (shaded box)

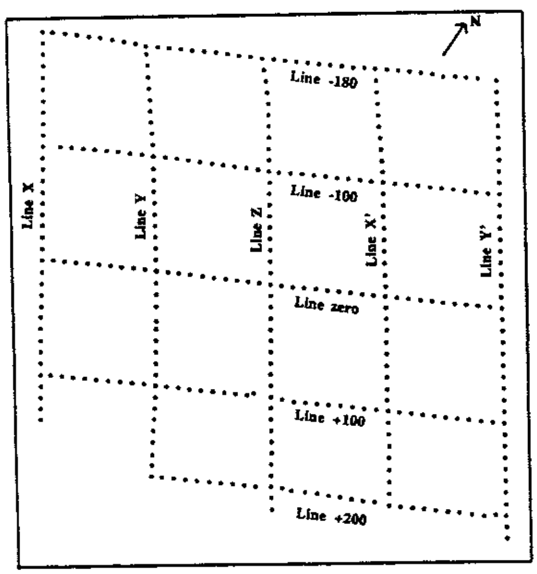


Figure 2: map of the grid

## METHODS

The selected study area was grided with ten lines; each of these lines had data points marked every 10 meters. Lines are named as shown in figure 2. Point zero is near the center of each line, and positive data points trend southwest. The grid was surveyed with a total field station to obtain an accurate grid map. Every point on the grid was surveyed three times on different days with the EM-31D and twice with the VLF receiver. Data was contoured on the grid map.

The EM-31D measures ground conductivity within the first six meters bellow the surface. This instrument transmits a magnetic field and detects electrical fields. If a conductive body is not present, then the EM-31D detects only the primary voltage created by the magnetic field it transmits. Over conductive terrain, the magnetic field causes current flow in a conductive body. This current results in a secondary magnetic field which creates a secondary current in the receiver. A more conductive body produces a stronger secondary current, and the intensity of the EM-31D measurement is directly related to ground conductivity (Sheriff, 1989).

The VLF receiver also operates on the principle that an electric field generates a magnetic field and vice-versa. Very Low Frequency radio waves produce a horizontal magnetic field. When VLF waves intersect a conductive body they generate a secondary electric and magnetic field. The secondary magnetic field is combined with the original VLF magnetic field to produce a resultant field. A polarization ellipse models the resultant field, and the characteristics of the ellipse are measured by the VLF receiver. Tilt is 100 times the tangent of the inclination of the polarization ellipse, and ellipticity is 100 times the ratio of minor to major axis of the polarization ellipse; the unit of both measurements are in percent (Kauahikaua et. al., in press). The profile of a lava tube is typically an antisymmetric curve for both tilt and ellipticity.

## RESULTS

The EM-31D profiles of every grid line were measured on August 1, 7, and 14. Each of these data sets was contoured, and these contours outline the general geometry of tube features less than six meters below the surface. The EM-31D contour map for August 1, has a moderately intense anomaly where the tube enters the grid, and a central region of high EM-31D readings. A bud with moderately intense readings is to the North of this central region, and a broad area of low ground conductivity extends to the southwest side of the map (figure 3). The intensity of the EM-31D anomalies is constrained by the amount of lava beneath the data point and the depth of that lava. The EM-31D anomaly decreased in intensity in the August 7 and 14 contour maps, but the geometry did not change. The decrease in anomaly intensity is illustrated by the EM-31D profile of Line Z (figure 4). All the peaks in Line Z decline in intensity with time, but the section of the profile between -200 and -50 meters decreases more rapidly than other peaks on this line. The percent decline in the height of peaks was calculated on all profiles The bud to the northeast of the main tube shows a greater percent decrease in peak maximums than other parts of the tube system.

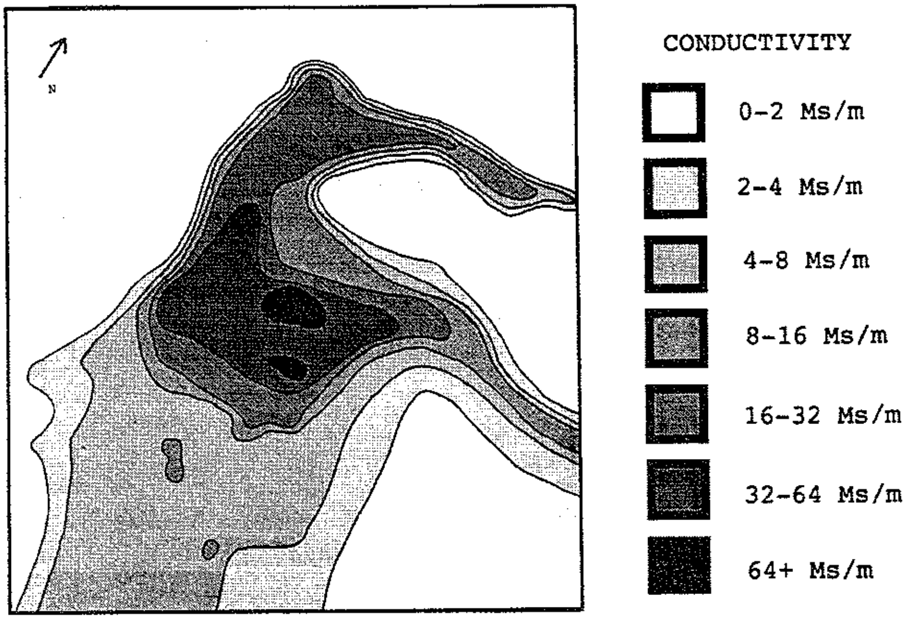


Figure 3: EM-31D contour map for August 1, 1996

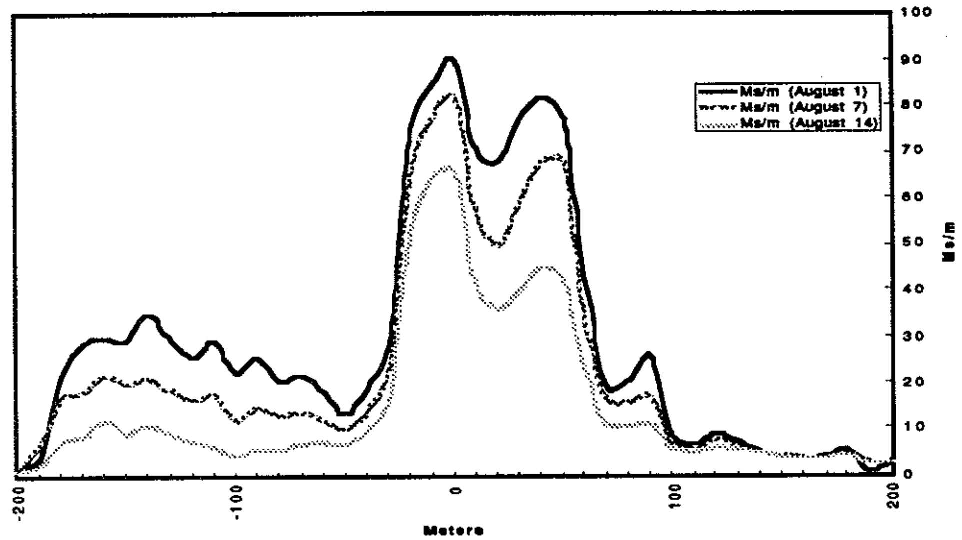


Figure 4: EM-31D profiles for Line Z

A profile of the VLF anomaly typically associated with a lava tube is illustrated in the July, 30 profile of Line X' (Figure 5). The center of the tube is located at the zero cross over (located between 60 and 70 meters on the Line X' profile). This anomaly appears in map view as an area of high positive values bordered by a region of low negative values. As with the EM-31D map, the VLF map shows the tube entering the grid on the northwest side (Figure 6). The VLF anomaly shows the tube branching off in three directions at the center of the grid. A weak anomaly is found at the location of the bud shown by the EM-31D data, a strong linear anomaly exits the grid at Line +200, and a moderate anomaly shows a section of the tube exiting through Line X. VLF data was used to locate tube features too deep to be detected with the EM-31D, and a comparison of data from both instruments gave depth of the tube relative to the six meter depth limitation of the EM-31D. When the two VLF data sets are compared, a decline in anomaly intensity is observed between the July 30-August 2 and the August 13 data set. Cross-sectional conductivity (cross-sectional area X conductivity) has been computed from VLF data, and a general trend of decreasing cross-sectional conductivity with time is apparent.

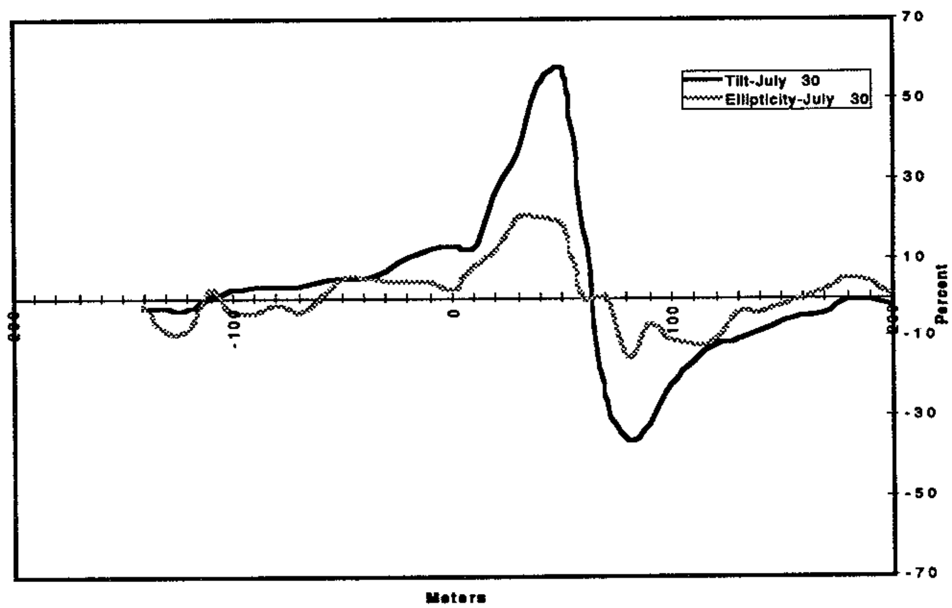


Figure 5: VLF profile of Line X'

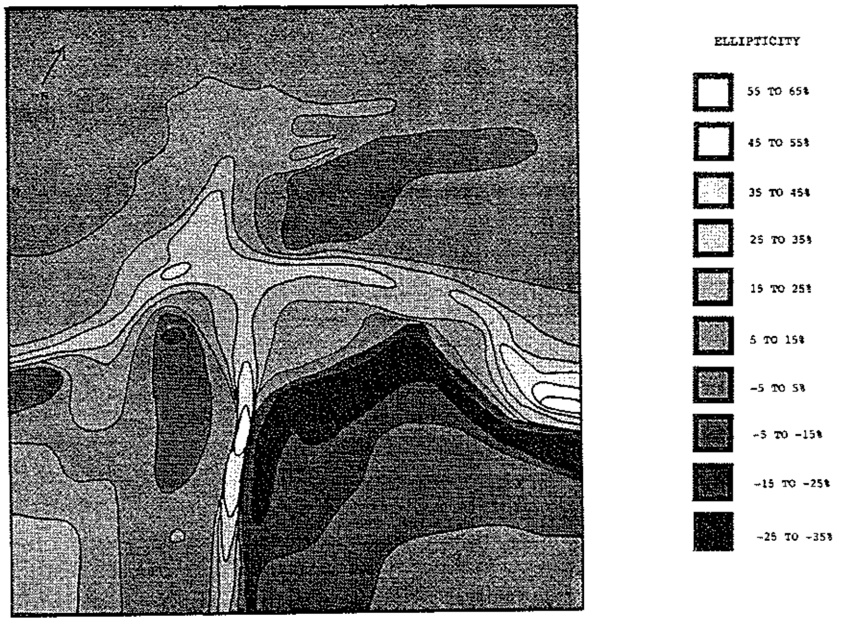


Figure 6: VLF Contour map for July 30-August 2

## Conclusions

Electromagnetic data show the study area is a morphologically complex section of the tube system. The tube enters the grid from the northwest and shallows as it flows towards the center of the grid. At the center of the grid, the main tube makes a turn of almost 90 degrees and exits the grid to the southwest; this section of the tube is at least six meters below the surface. A rapidly cooling, shallow bud, containing very little flowing lava is located North of the main tube. Another branch or bud of the tube is more than six meters deep, and exits the tube along the southeast side of the grid. The intensity of electromagnetic anomalies declines during the study period, indicating that this tube may become inactive subsequent to the study. Indeed, on August 21, 1996 there was a pause in eruptive activity from the Pu'u O'o vent, and following this pause the West Liapuki branch of the tube system was not reoccupied.

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