UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SELF-POTENTIAL SURVEYS RELATED TO PROBABLE GEOTHERMAL ANOMALIES, HUALALAI VOLCANO, HAWAII

By

Dallas B. Jackson
and
Maurice K. Sako

U.S. Geological Survey
Hawaiian Volcano Observatory
Hawaii National Park, HI 96718-0051

Open-File Report 82-127

INTRODUCTION

As an extension of successful self-potential (SP) studies on Kilauea Volcano (Zablocki, 1976), several exploratory SP traverses were made across the northwest rift zone of Hualalai Volcano in 1980. Our initial results showed areas of high-amplitude positive anomalies similar to those on Kilauea that are well-correlated with heat sources related to eruptive fissures or shallow intrusions (Zablocki, 1976; Hawaiian Volcano Observatory, unpublished data). The initial profiles were so encouraging that in early 1981 the exploratory traverses were linked with a 22 km tie line, and one additional cross-rift profile was added in an area of interest northwest of the summit. This report summarizes the results of our SP surveys to date and explains the rationale for adding a topographic adjustment to the profile and contoured data.

COMPARISONS BETWEEN HUALALAI AND KILAUEA VOLCANOES

Both Kilauea and Hualalai are active volcanoes although Hualalai is much older than Kilauea with a correspondingly much longer eruption recurrence interval. Hualalai's last flows issued from vents at 1830 m (6000 ft.) elevation near Kaupulehu Crater (fig. 1) on the northwest rift in 1800 and from Puhia Pele, also on the northwest flank at about 460 m (1500 ft.) elevation, in 1801 (Puhia Pele is about 3 km off the northwest corner of figure 1 along the rift zone).

Hualalai, unlike Kilauea, has no summit caldera, although the pile of alkalic basalts that caps the volcano presumably covers an older tholeiitic shield similar to those of Kilauea and Mauna Loa. Perhaps because it is older and capped by slightly more viscous alkalic lavas the overall topographic gradients are very much steeper than those of Kilauea, although R.B. Moore (U.S.G.S, personal communication) believes the steep rift topography results from either buried trachyte domes or a large number of buried basaltic vents concentrated in the rift zone.

Hualalai, like Kilauea, has well-defined rift zones. The principal rift runs northwest-southeast with an apparent "bend" to the south at the southeast end. A subsidiary rift, trending approximately north, branches from the main northwest rift at the summit near Hainoa Crater ("HC" on fig. 8). The north rift becomes diffuse away from the summit although a vent on the rift (and off the map) erupted copious amounts of trachyte. The northwest-southeast rift zone of Hualalai is at the center of the pronounced topographic ridge of the volcano, along which are concentrated many cinder cones, spatter ramparts, and pit craters. Because of the relative narrowness of the volcano's ridgelike form, its SP anomalies extend well down the steep sides. Kilauea, by comparison, is subdued topographically, except for the steep region of gravity faults along the south flank (Swanson and others, 1976), with nearly imperceptible topographic gradients along the axes of the rifts where the large SP anomalies related primarily to fissure-type eruptions are found (Zablocki, 1978, fig. 17; Hawaiian Volcano Observatory, unpublished data). Nearly all the large SP anomalies on Kilauea occur over nearly level terrain.

TOPOGRAPHIC EFFECTS

Strong correlations between positive topographic gradients and negative self-potential fields produced by subsurface water (streaming potentials)* have been cited as a reasonable explanation for self-potential anomalies in Yellowstone Park (Zohdy and others, 1973), Long Valley Caldera, Calif. (Anderson and Johnson, 1976), and on Kilauea Volcano (Zablocki, 1976).

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*For a summary of streaming potential and other possible source mechanisms see Corwin and Hoover, 1979.

Zablocki (1977) noted a correlation between elevation change and SP gradients of -1.8 mv/m on the lower east rift zone of Kilauea and a 600 mv difference between the ground surface and the high-level water table in a research drill hole in the south summit area of Kilauea--a gradient of -1.35 mv/v. An example of a similar correlation was noted by Corwin and Hoover (1979, their fig. 3) for Adagdak Volcano, Adak Island, Alaska, where the lower slopes of the volcano show a topographically related SP gradient of about -2 mv/m; the upper slopes have an exceptionally steep gradient of about -10 mv/m.

At Kilauea we have also noted additional correlations between topographic and self-potential gradients in the 1 to 2 mv/m range. The summit of Kilauea (at the Hawaiian Volcano Observatory) is -1500 mv relative to the ocean at Punaluu Beach (-1.23 mv/m) about 40 km distant, and on the central east rift zone a strong correlation of -1.72 mv/m (fig. 2) was noted on a 15 km traverse from the ocean on the southeast (Kupapau tide gauge) to a subdivision (Eden Roc) across the rift zone to the northwest. The zone of highly correlated topographic-SP gradients extends from the ocean on the southeast and up the gravity faults of the steep south flank (a horizontal distance of about 5 km). The abrupt decrease in negative potentials begins at about the 500 m elevation approximately at the southeast edge of the active rift. In figure 2, the linear linear negative gradient on the left implies that no high level water exists along the profile line between the coast and the 550 m elevation on the south flank of the rift; a conclusion supported by a DC sounding several kilometers to the west (Hawaiian Volcano Observatory, unpublished data).

Zablocki (1978) has proposed that streaming potentials, like the foregoing examples, resulting from the descent of meteoric water through the vadose zone are a probable source mechanism for the SP anomalies on Kilauea. The mechanism that Zablocki proposes assumes that surface potential intensities are proportional to the thickness of the vadose zone, and positive anomalies (i.e., positive relative to the surrounding area) reflect the shallow depth to which water may descend before being diverted by thermal fluids rising above a deep heat source. Furthermore, the anomalies might be enhanced by ascending water vapor (steam). It seems reasonable to us that heat rising through fractures above a deep magmatic source (i.e., well below the water table) also might vaporize descending water such that rising thermal fluids (a convection cell) would be unnecessary for the source mechanism. In general, this scheme appears to fit most observations made at Kilauea, although it also seems probable that many of the SP highs (especially those having wavelengths of much more than a kilometer) may be due to high-level dike impoundment of groundwater with shorter wavelength features, possibly related to rising steam superposed on them. In figure 2, the only rift zone anomaly that is positive relative to the ocean occurs at the 1977 eruptive fissure where the five readings near the fissure are as much as 215 mv positive relative to sea level.

Self-potential data from Hualalai also seem to show much the same type of relation between self-potential fields and elevation (fig. 3) as do those from Kilauea. Figure 3 shows all the SP data on Hualalai relative to our present lowest reference station at the 1500 m (4900 ft.) level plotted against elevation. There is more scatter in the Hualalai data (fig. 3) than there is in the east rift data for Kilauea (fig. 2); however, the Kilauea data are for one profile crossing from well outside any anomalous region at sea level perpendicularly across a two-dimensional anomaly. In contrast, the Hualalai data set begins well up on the mountain and at no place do we know positively that we are clear of anomalous regions. Nevertheless, the left hand 11 km of profile A-A' (fig. 4) seems to show a general inverse relationship between self-potential fields and topography. The gradient line of -1.57 mv/m is based primarily on the section of profile from Waha Pele (WP) to just beyond Poikahi (POI) in figure 4. Trends of data points for other profiles (the remainder of A-A, and B-B' through F-F') diverge sharply from the -1.57 mv/m line because, like the expression of the east rift of Kilauea in figure 3, most of the profiles are anomalous and exhibit increasing rather than decreasing potential with increasing elevation. The majority of data points in profiles F-F' and G-G' lie well below the -1.57 mv/m gradient line, suggesting that the streaming potential coefficients may be greater northwest of the summit than they are at the summit or to the southeast.

TOPOGRAPHIC ADJUSTMENTS

Because of the steep topography on Hualalai, all data points were adjusted by 1.57 mv/m relative to point A' on figure 4 (the lowest point in elevation for the survey). The adjusted profiles are shown along with the observed data in figures 4 through 7. The most noticeable result of the correction is that all adjusted data points have become more positive because they are all topographically higher than reference point A' 1 km south of Waha Pele. Other changes caused by the topographic adjustments are seen on the line A-A' (fig. 4). The most dramatic change is the removal of the monotonic decrease in SP between point A' and the 11 km mark. Less obvious, but probably more important, is the removal of the strong asymmetry from the Waha Pele and Poikahi anomalies that, if left in, could be mistaken for dipping source body effects. The third effect, already mentioned, is the increase in anomaly amplitude although anomaly wavelength is unaffected. The adjusted SP high that coincides with the summit is enhanced by about 270 mv (25%) with respect to the unadjusted data.

SELF-POTENTIAL MAP

The map of the adjusted self-potential data (fig. 8) is drawn to the same base as figure 1, although SP contours replace the topographic contours and traverse line labels are deleted. The SP map is referenced to the same base 1 km south of Waha Pele as are the adjusted SP profiles (figs. 4 through 7), and the two data sets may be compared directly. Control for the map contouring is, of course, the long tie line traverse (A-A') and the various cross-rift profiles (B-B' through G-G'). Let the reader beware. The contouring is not dashed everywhere that it is subjective. The most obvious of these places is downrift of Kaupulehu Crater (traverse G-G') where we have no control, but it seems reasonable to project the contours as shown. The major features of the map, although not tightly controlled, are well enough controlled that there is little doubt as to primary trends and contour projections.

The SP map may be divided into three sections of interest; the interest coefficient increases from southeast to northwest. The first section is approximately bounded on the west by Poikahi (POI) and includes all the area to the east. In terms of profile data, this includes from A' to about the base of the anomaly labeled "POI" (fig. 4) and profiles B-B' and C-C' (fig. 5). This part of the rift has lower amplitude anomalies than the summit region and both lower amplitude and longer wavelength anomalies than the area northwest of the summit. The only area of interest seems to be near Waha Pele where a broad, low amplitude (~300 mv) anomaly (that trends about east-west) coincides with perhaps the youngest vent in that part of the rift (probably 17th century, R. B. Moore, USGS, personal communication). Profile B-B' is relatively featureless and without the A-A' tie line, the Waha Pele anomaly would not have been defined. Profile C-C' has two monopolar anomalies (or one dipolar anomaly depending on how one cares to look at them). We believe the C-C' profile anomalies to be monopolar because the larger one on the right coincides with Poikahi and the smaller one on the left lies near, although offset somewhat to the south of, the vent marked "J" (fig. 1).

The next section of interest extends from about the uprift side of Poikahi, approximately where tie line A-A' crosses the topographic rift near Poikahi, and across the summit area nearly as far as profile F-F' (fig. 6b). The anomalies appear to be broader than farther to the west and the amplitudes greater. Profile E-E' is the only cross-rift anomaly that is nearly complete in this region with an adjusted anomaly amplitude of about 1 volt. The smoothness of the profile may be deceptive since it is probably a compound anomaly composed of several shorter wavelength features. There is a suggestion of another source superposed on the right flank of the main anomaly at the 1000 mv level where a reversal in slope coincides with the vents about 0.6 km due north of Hainoa Crater (other positive features on the right limb of the uncorrected SP profile disappear in the topographically adjusted profile).

Northeast of Hainoa Crater and on line with Kileo Crater (KIL) is a ridgelike high that coincides with the north rift zone. No profiles cross it away from the summit area although what little control we have definitely suggests it is more positive than the slopes of the mountain adjacent to it.

The third section of interest lies between profiles F-F' and G-G' (figs. 7a and 7b). In this area, the vent distribution is less diffuse than in the two areas to the southeast (described above) and the self-potential expression of the rift is also tighter. In a sense these anomalies are very much like the east rift and southwest rift zone anomalies on Kilauea that can be correlated with recent eruptive fissures or shallow intrusions. On Kilauea these types of anomalies typically are monopolar and have relatively short wavelengths and steep limbs, showing that the tops of the sources are rarely more than a few hundred meters deep. Along profile F-F' (fig. 7b) the separation between adjacent monopolar anomalies is quite clear; each anomaly coincides with a vent or pit crater. The highest amplitude anomaly on profile F-F' (~550 mv) appears to coincide with the slightly higher amplitude (~750 mv) but equally shallow source anomaly at Kaupulehu Crater (G-G'), near the site of the 1800 eruption. Based on the extent of the steepest slope, the depth to the top of the source of each anomaly cannot be much more than 200 meters. If these two anomalies are analogous to similar anomalies on Kilauea, then it is probable that at least the portion of the rift between profiles F-F' and G-G' still is underlain by an active heat source at depth and the depth to the top of the SP source is very shallow.

SUMMARY

Although Hualalai is a volcano in a much later stage of development with far fewer eruptions (the only historic eruptions being in 1800 and 1801) than Kilauea Volcano, it has a self-potential expression very similar to Kilauea where virtually every positive anomaly can be related to a heat source.

Unlike Kilauea, Hualalai is not topographically subdued, and anomaly shape and amplitude are affected by the steep surface gradients. Comparison of topographic gradients with self-potential fields on Hualalai suggests that for the southeastern and summit areas a topographic correction of approximately 1.6 mv/m is probably valid and should be made to all the data. Northwest of the summit, elevation and SP correlations (data for profiles F-F' and G-G', fig. 3) suggest that the streaming potential coupling coefficient is larger than farther east, and the topographic adjustments should probably be larger than the 1.6 mv/m that was used. To define what the adjustment should be, a profile away from the rift below Kaupulehu Crater is needed.

Subdued SP anomalies are characteristic of the rift zone southeast of the summit area, and the south-trending portion of the rift towards Waha Pele is virtually devoid of SP expression except for the diffuse Waha Pele anomaly.

The low amplitude anomalies in this region suggest that the SP source intensity has decreased probably because the heat source at depth has cooled or continuity to it has been lost.

The summit of Hualalai has a high amplitude, rather broad wavelength anomaly associated with it (centered on Hainoa Crater) that may be composed of numerous short wavelength anomalies. If one considers it as a single anomaly then the top of the source depth is probably about 0.5 km deep and may reflect high-level dike-impounded water beneath the summit.

West of the summit, anomalies are definitely separable, and each positive anomaly can be correlated to a vent or pit crater. The narrow positive feature running down the center of the rift is coincident with Kaupulehu, near the site of the 1800 eruption, and strongly suggests a heat source at depth is still present and has continuity to the near surface.

RECOMMENDATIONS FOR FUTURE STUDIES

1. Additional SP profiling should be done in the summit area to better define the character of the summit anomalies and to map at least the upper part of the north rift, as far as Puu Waawaa Crater.

2. The remainder of the northwest rift from Kaupulehu to the ocean should be crossed with several profiles to see how far downrift the narrow high amplitude anomaly extends.

3. A tie line to the ocean should be established so that all data are referenced to the ultimate base line in these islands.

4. Additional electrical geophysical surveys, both vertical electrical soundings (VES) and electromagnetic soundings, should be made to attempt to separate hot-lower resistivity zones from cool-higher resistivity zones.

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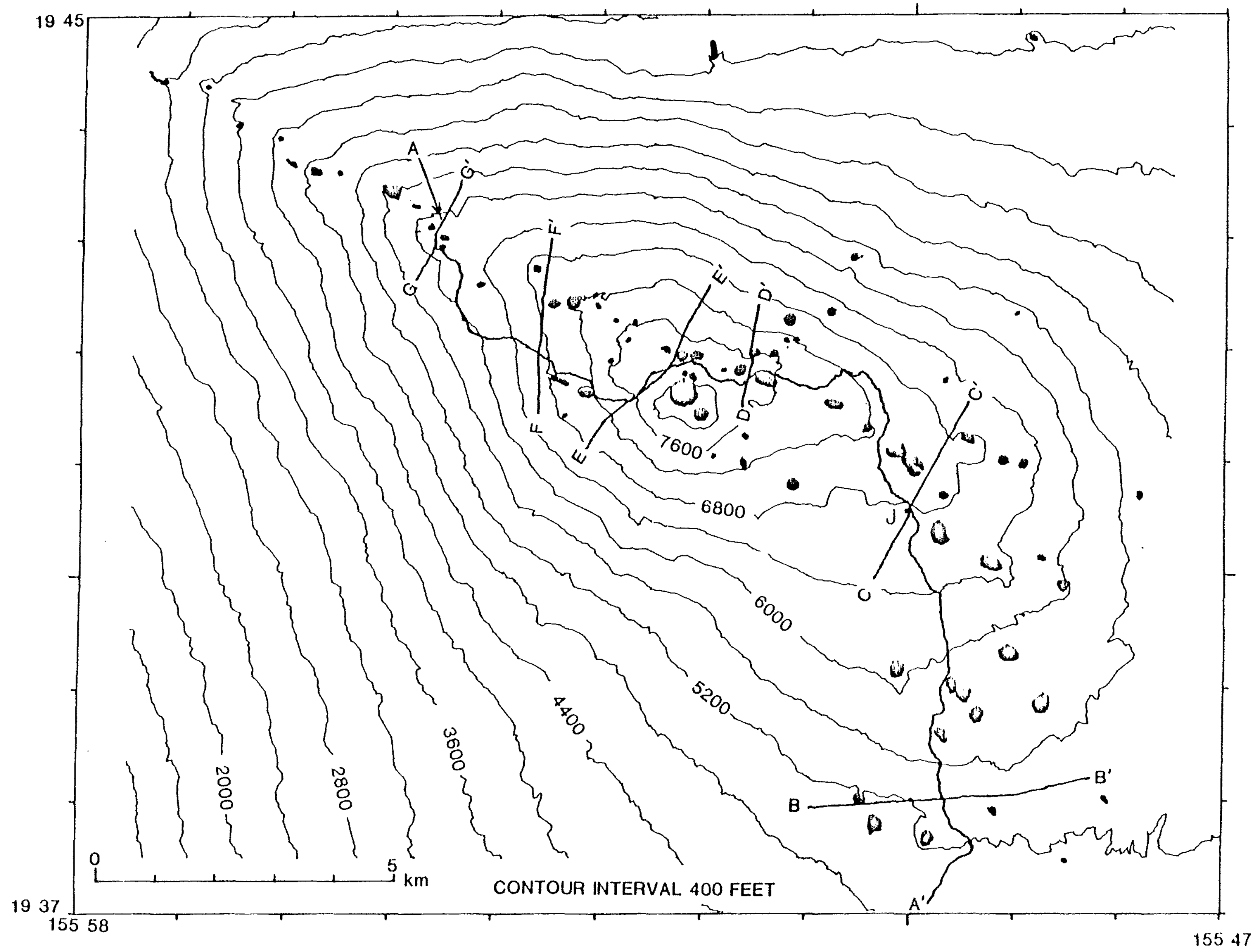

Figure 1. Location map of self-potential (SP) profiles on Hualalai Volcano. SP profile lines are identified by letter pairs from A-A' to G-G'. Solid black features are vents and pit craters of the rift zones.

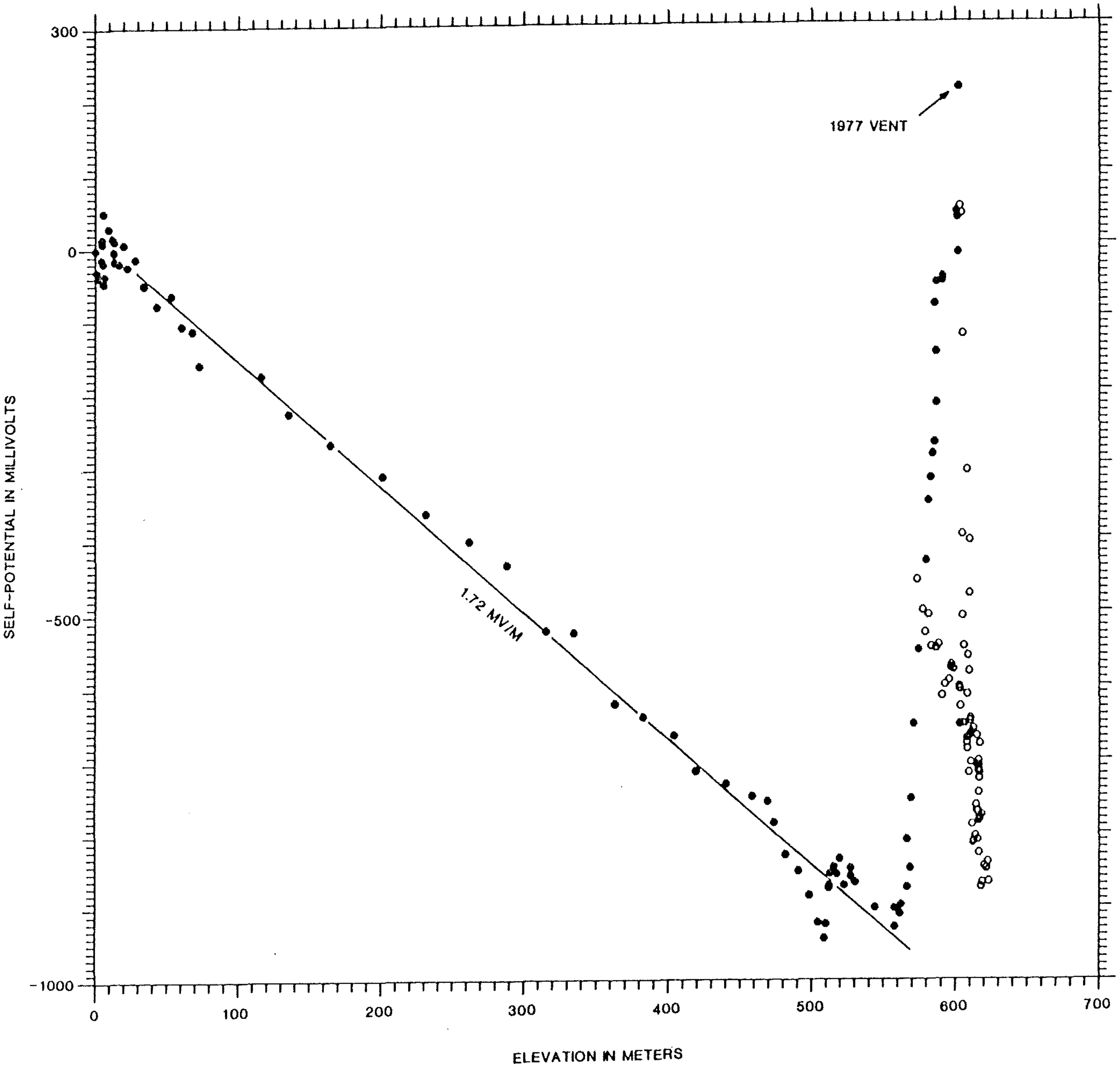

Figure 2. Self-potential in millivolts versus ground elevation in meters, middle east rift zone, Kilauea Volcano, Hawaii.

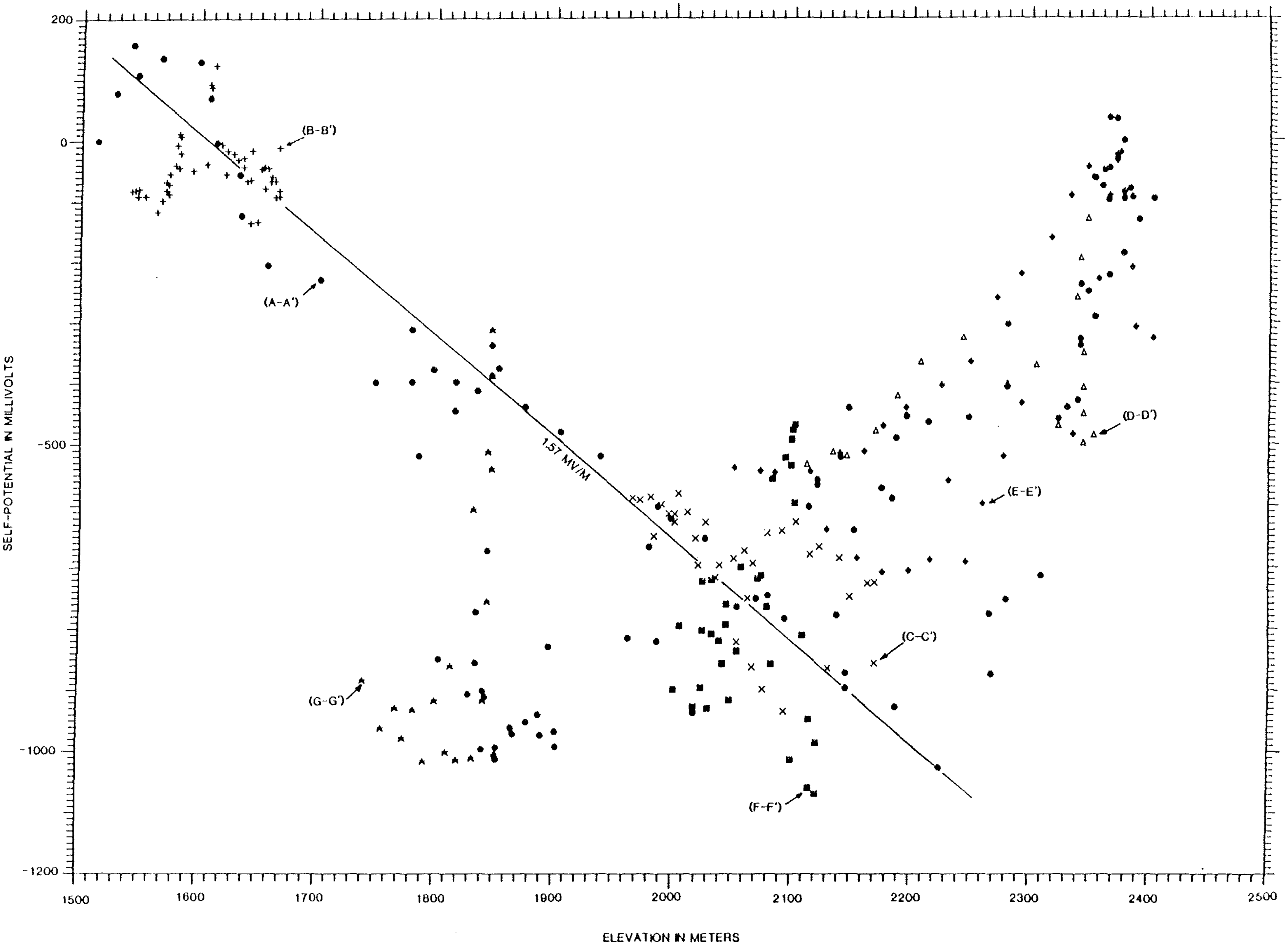

Figure 3. Self-potential in millivolts versus ground elevation in meters, Hualalai Volcano, Hawaii. Data for each SP profile on the volcano has a different symbol and the profile designation is in parenthesis.

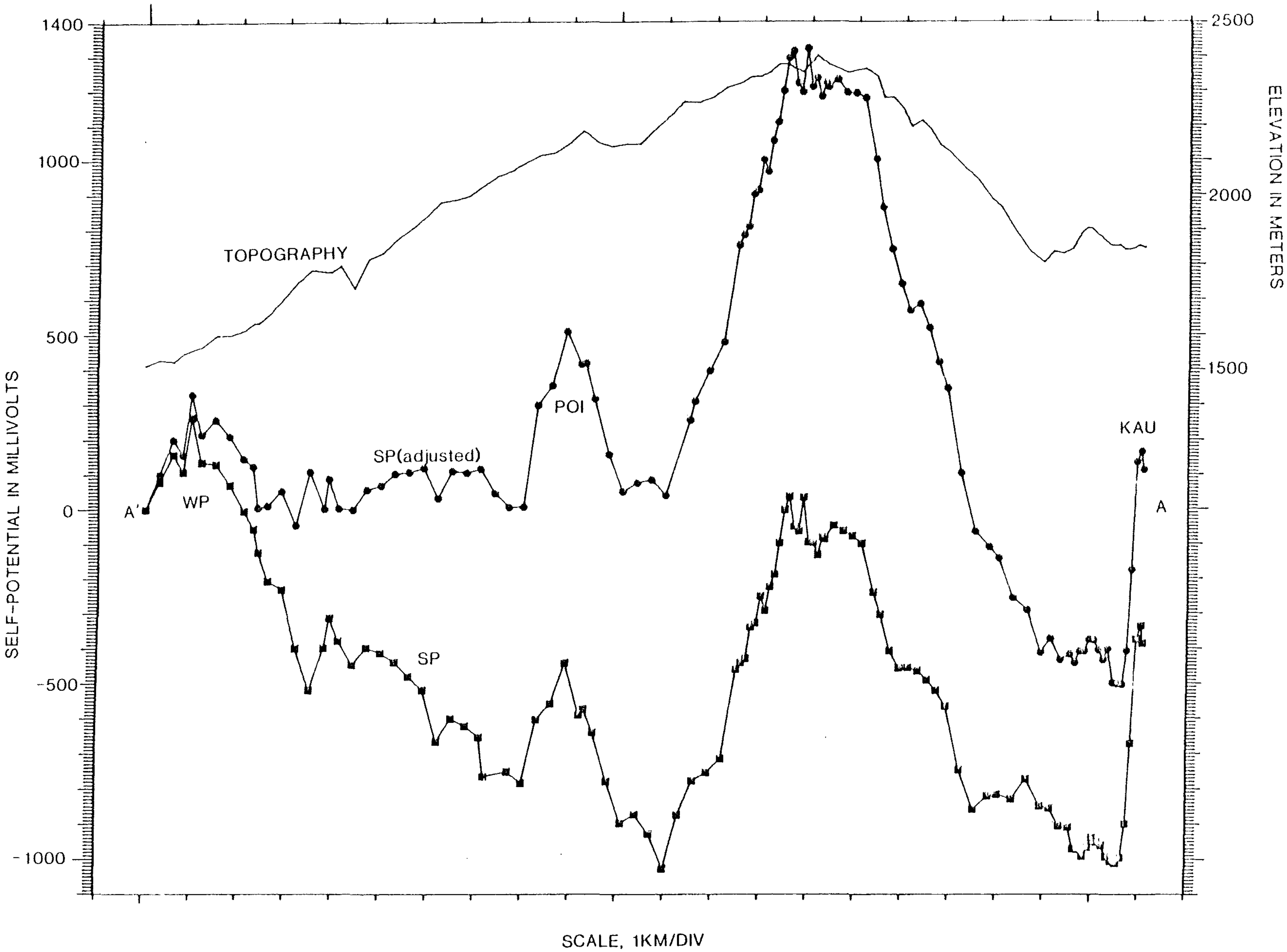

Figure 4. Profile A-A' from Kaupulehu Crater to Waha Pele Crater. Solid squares are measured SP readings; solid circles are SP readings adjusted for a topographic correction of 1.57 mv/m. The reference for all SP data on Hualalai is at A' 1 km south of Waha Pele.

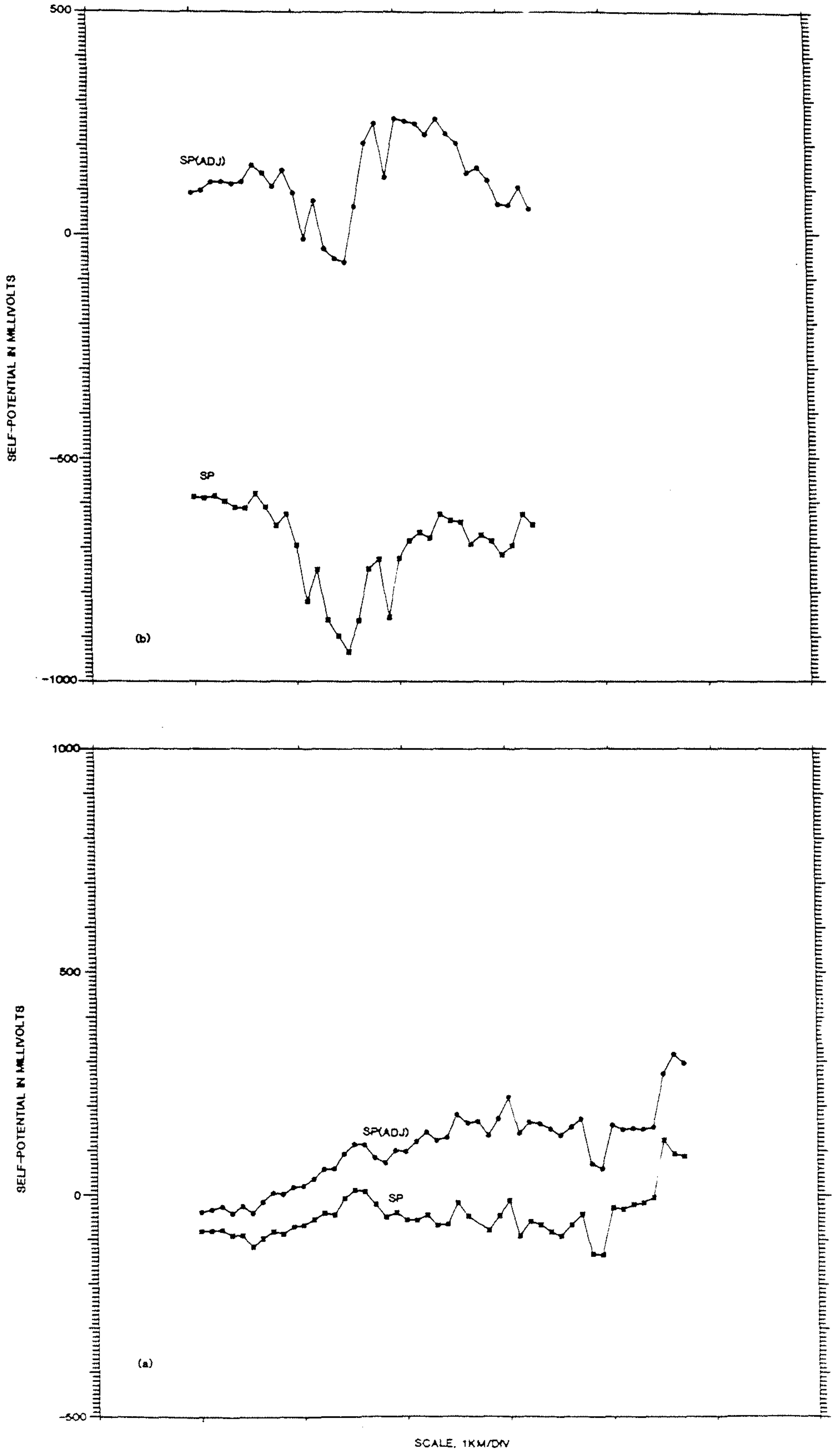

Figure 5. Profiles B-B' (5a) and C-C' (5b), southeast flank of Hualalai. Adjusted profiles are corrected by 1.57 mv/m relative to the Waha Pele reference.

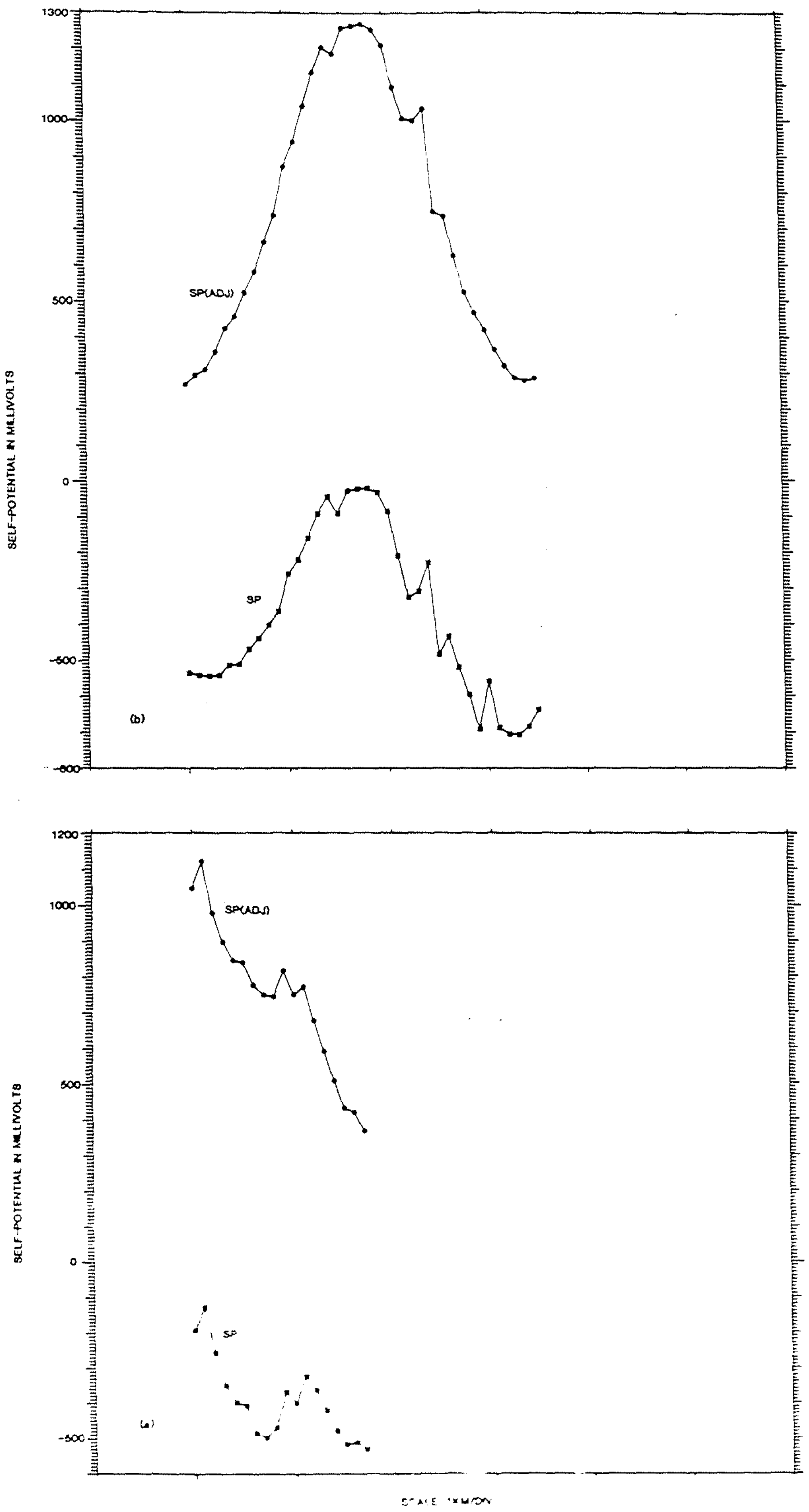

Figure 6. Profiles D-D' (6a) and E-E' (6b), summit area of Hualalai. Adjusted profiles are corrected by 1.57 mv/m relative to the Waha Pele reference.

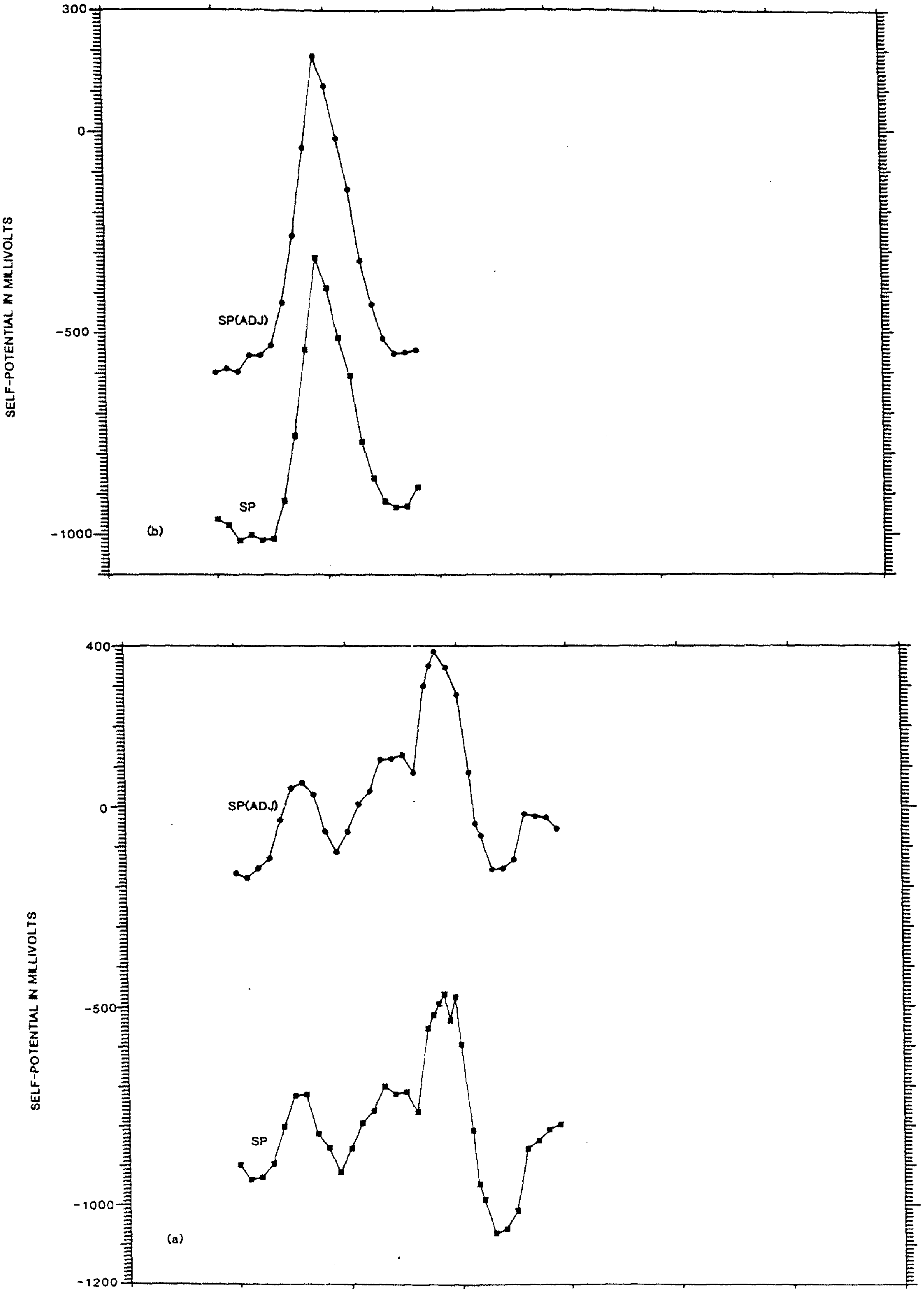

Figure 7. Profiles F-F' (7a) and G-G' (7b), northwest ridge of Hualalai. Adjusted profiles are corrected by 1.57 mv/m relative to the Waha Pele reference.

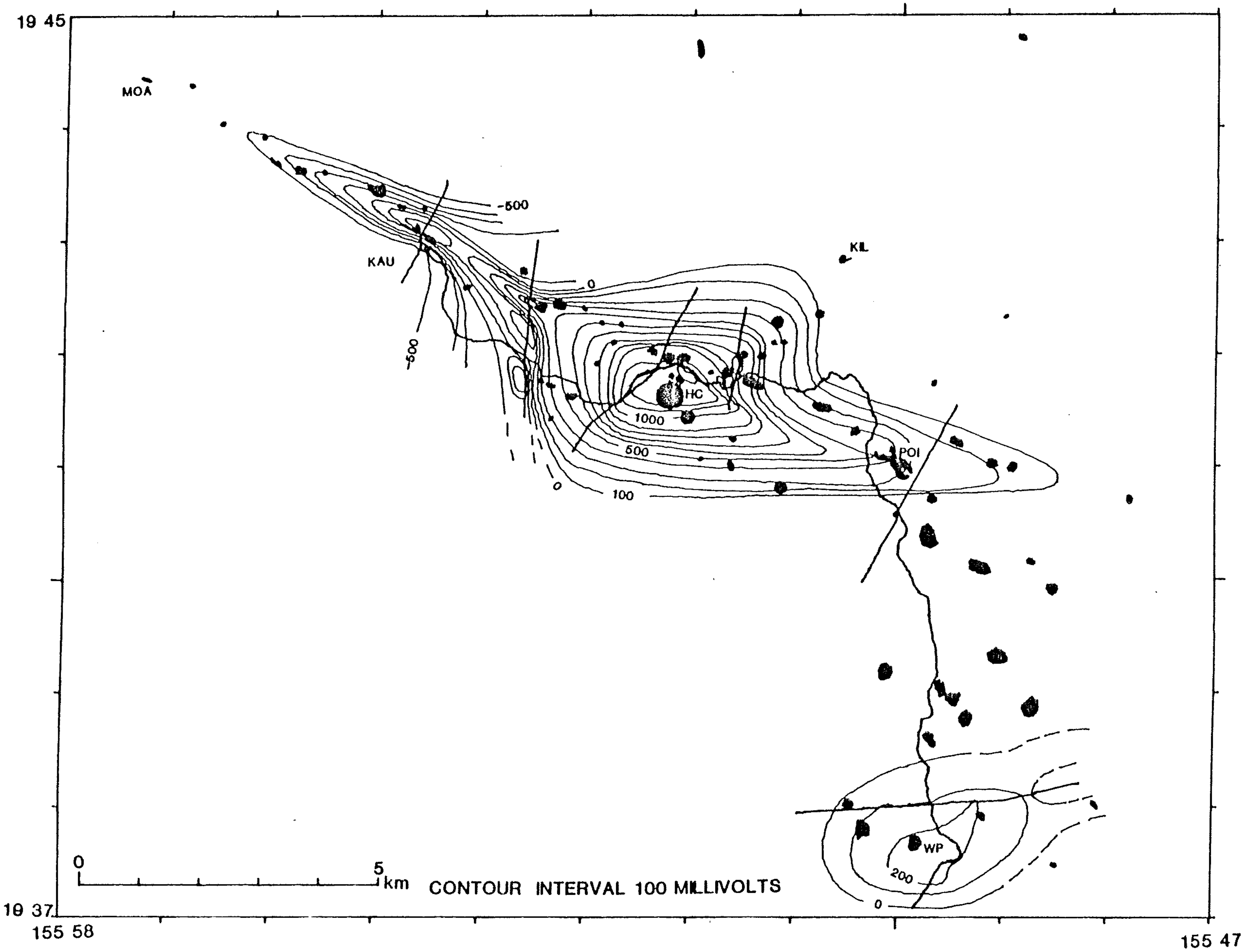

Figure 8. Self-potential map of part of the northwest rift zone of Hualalai. MOA (Moanuiahea), KAU (Kaupulehu Crater), HC (Hainoa Crater), POI (Poikahi Crater), J (unnamed vent), and WP (Waha Pele Crater).