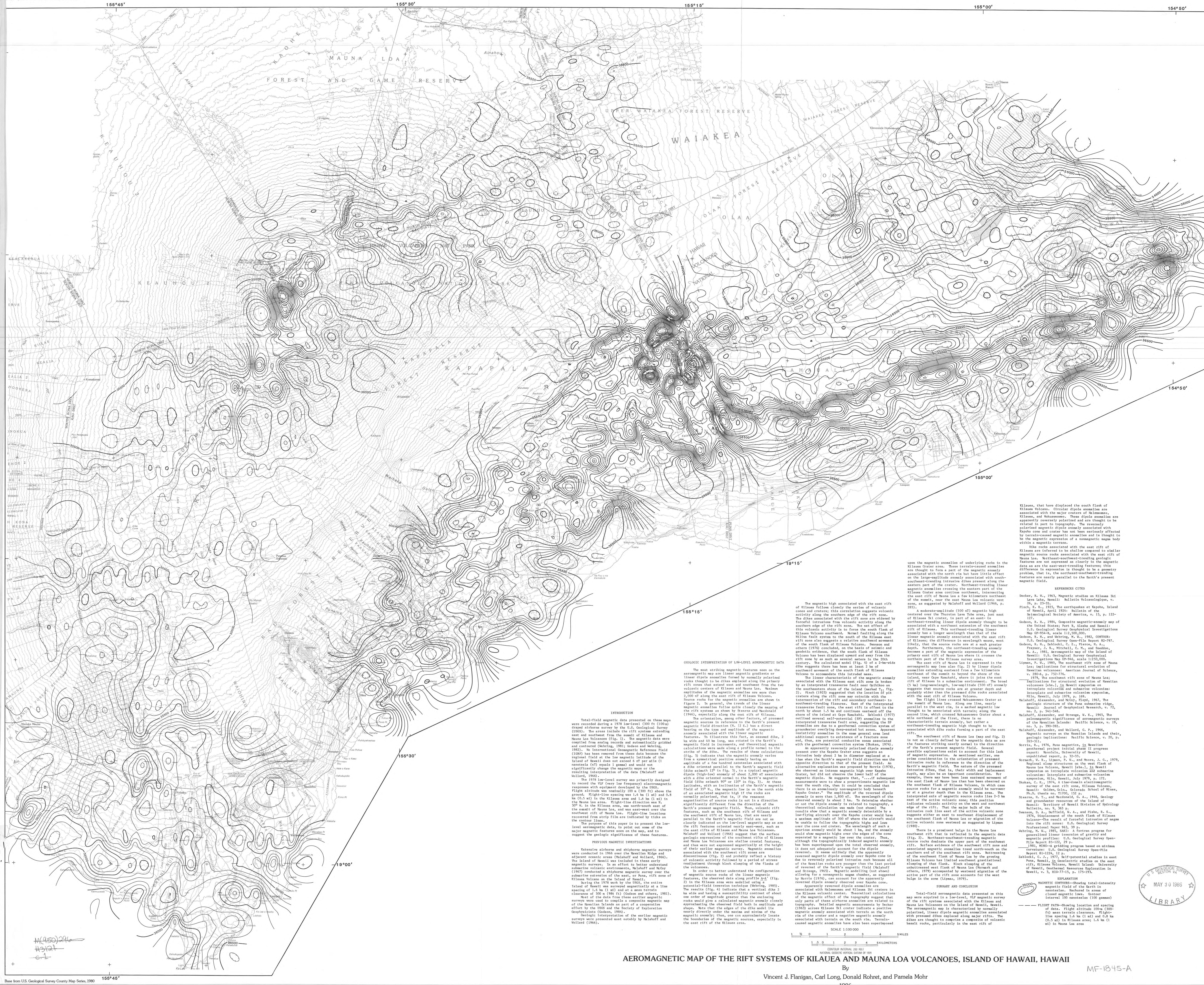

Base from U.S. Geological Survey County Map Series, 1980

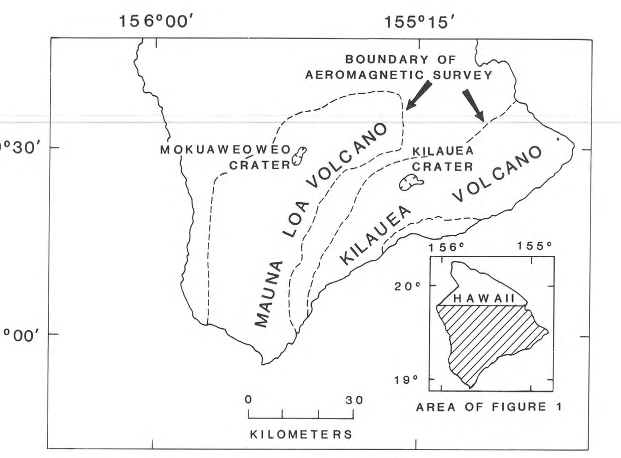

Figure 1.--Index map of Island of Hawaii showing location of low-level aeromagnetic survey in areas of Kilauea and Mauna Loa Volcanoes.

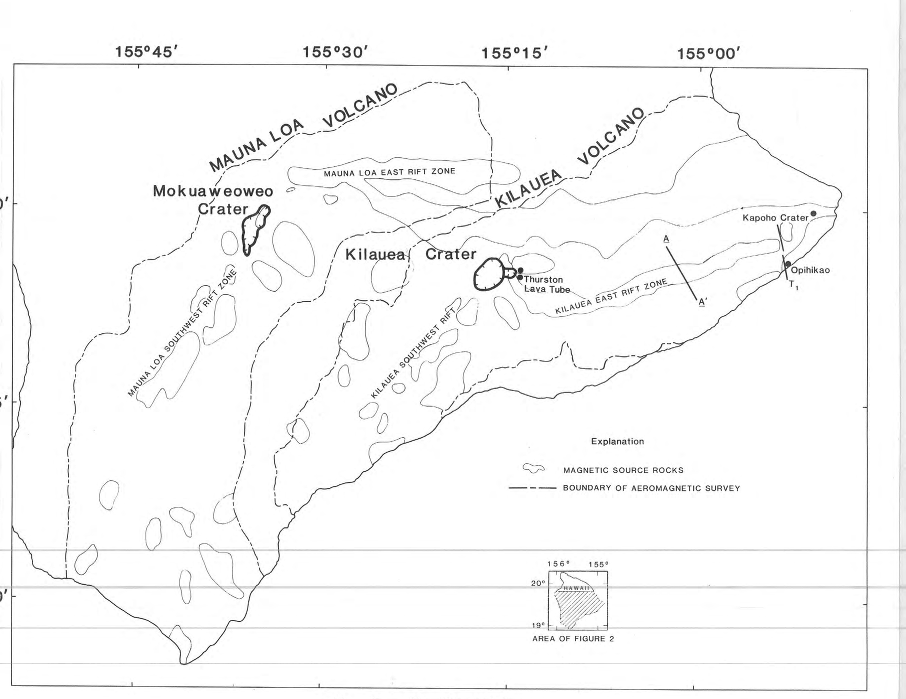

Figure 2.--Map of aeromagnetic survey areas of Kilauea and Mauna Loa Volcanoes showing locations of magnetic source rocks.

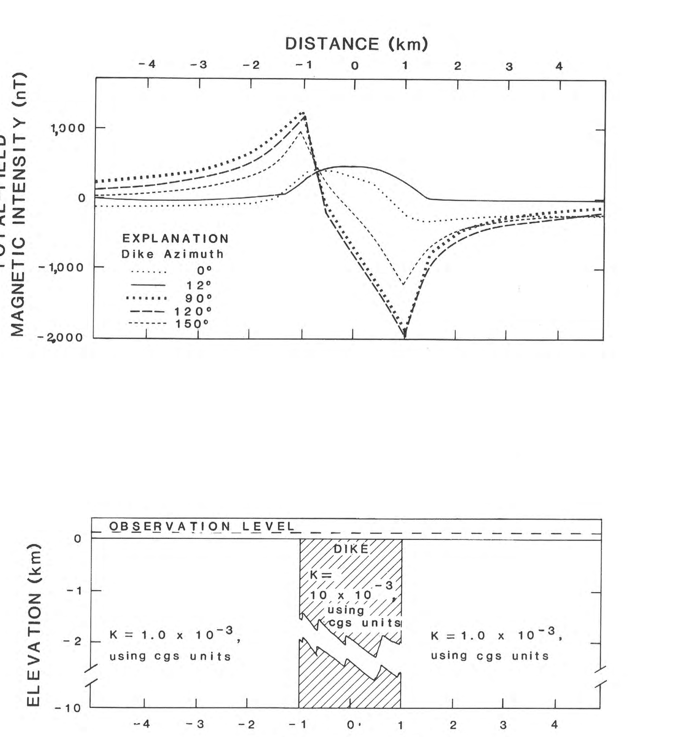

Figure 3.--Theoretical magnetic models of dike rocks rotated in Earth's magnetic field showing relative amplitude and anomaly shape. Remanent magnetism is parallel to direction of Earth's present magnetic field. Inclination and intensity of Earth's magnetic field is 35° and 36000 nT, respectively; K, magnetic susceptibility.

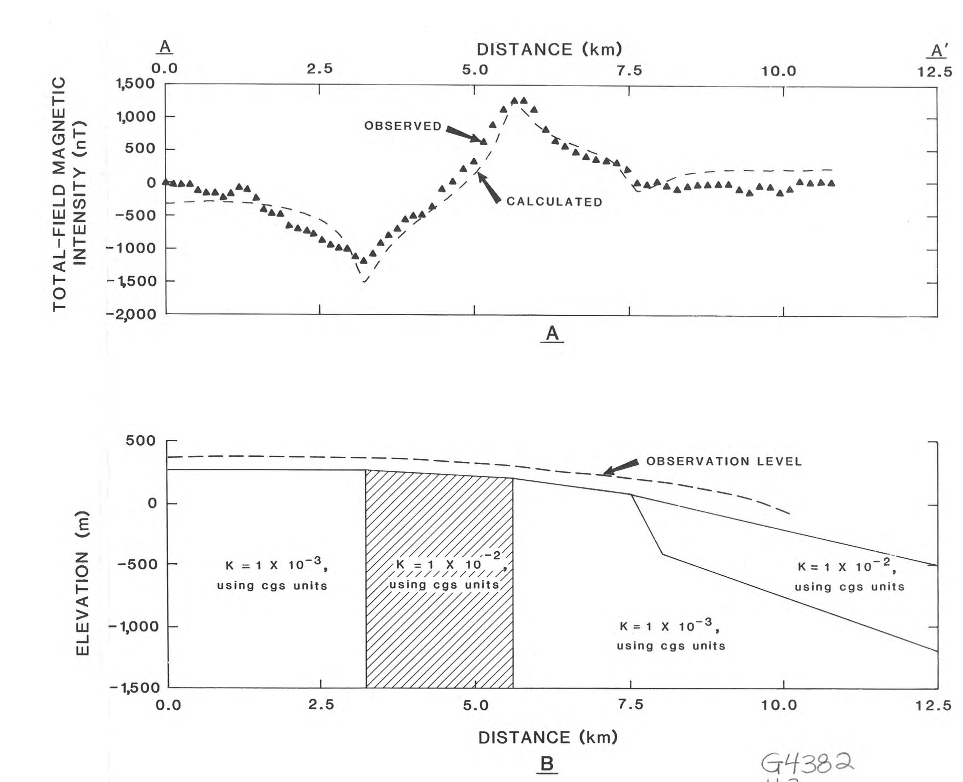

Figure 4.--Magnetic model along profile A-A' (fig. 2). A, Triangles are observed data, dashed lines are calculated magnetic response for bodies shown in B. Magnetic susceptibilities (K) are as shown. B, model representing magnetic dike rocks (shaded) between basalt flows of lower bulk magnetism than the dike.

INTRODUCTION

Total-field magnetic data presented on these maps were recorded during a 1978 low-level (300 ft (100 m) draped airborne survey by the U.S. Geological Survey (USGS). The areas include the rift systems extending east and southwest from the summit of Kilauea and Mauna Loa Volcanoes (fig. 1). The magnetic data were compiled from analog records and automatically gridded and contoured (Webring, 1981; Godson and Webring, 1982). No International Geomagnetic Reference Field (IGRF) has been removed from these data because the regional field at the low magnetic latitude of the Island of Hawaii does not exceed 6 nT per mile (1 nanotesla (nT) equals 1 gamma) and would not significantly change the magnetic maps or the resulting interpretation of the data (Malahoff and Wollard, 1966).

The 1978 low-level survey was primarily designed to record the VLF (very low frequency) electromagnetic responses with equipment developed by the USGS. Flight altitude was nominally 100 m (300 ft) above the ground. Flight-line spacing was 1.6 km (1 mi) and 0.8 km (0.5 mi) in the Kilauea area and 1.6 km (1 mi) in the Mauna Loa area. Flight-line direction was N. 30° W. in the Kilauea area, was north-south east of the summit of Mauna Loa, and was east-west over the southwest rift of Mauna Loa. Flight-line locations recovered from strip film are indicated by ticks on the contour lines.

The purpose of this paper is to present the low-level aeromagnetic data, to point out some of the major magnetic features seen on the map, and to suggest the geologic significance of these features.

PREVIOUS MAGNETIC INVESTIGATIONS

Extensive airborne and shipborne magnetic surveys were conducted in 1966 over the Hawaiian Ridge and adjacent oceanic areas (Malahoff and Wollard, 1966). The Island of Hawaii was included in these early magnetic surveys. In an effort to better understand submarine volcanic environments, Malahoff and McCoy (1967) conducted a shipborne magnetic survey over the submarine extension of the east, or Puna, rift zone of Kilauea Volcano on the Island of Hawaii.

During the 1978 work by the USGS, the entire Island of Hawaii was surveyed magnetically at a line spacing of 1.6 km (1 mi) and at a mean terrain clearance of 300 m (984 ft) (Godson and others, 1981).

Most of the data from these earlier magnetic surveys were used to compile a composite magnetic map of the Hawaiian Islands as part of a cooperative effort by the USGS and the Society of Exploration Geophysicists (Godson, 1984).

Geologic interpretation of the earlier magnetic surveys were presented most notably by Malahoff and Wollard (1966).

GEOLOGIC INTERPRETATION OF LOW-LEVEL AEROMAGNETIC DATA

The most striking magnetic features seen on the aeromagnetic map are linear magnetic gradients or linear dipole anomalies formed by normally polarized rocks thought to be dikes emplaced along the primary rift zones that extend east and southwest from the two volcanic centers of Kilauea and Mauna Loa. Maximum amplitudes of the magnetic anomalies are more than 2,000 nT along the east rift of Kilauea Volcano. Source rocks for the magnetic anomalies are shown in figure 2. In general, the trends of the linear magnetic anomalies follow quite closely the mapping of the rift systems as shown by Stearns and Macdonald (1946), especially along the east rift of Kilauea.

The orientation, among other factors, of presumed magnetic sources in reference to the Earth's present magnetic field direction (N. 12 E.) has a direct bearing on the type and amplitude of the magnetic anomaly associated with the linear magnetic features. To illustrate this fact, an assumed dike, 2 km wide and 40 km long, was rotated in the Earth's magnetic field in increments, and theoretical magnetic calculations were made along a profile normal to the strike of the dike. The results of these calculations (fig. 3) indicate that the magnetic anomaly varies from a symmetrical positive anomaly having an amplitude of a few hundred nanoteslas associated with a dike oriented parallel to the Earth's magnetic field (dike azimuth 12° in fig. 3), to a typical magnetic dipole (high-low) anomaly of about 2,000 nT associated with a dike oriented normal to the Earth's magnetic field (dike azimuth 90° or 120° in fig. 3). At these latitudes, with an inclination of the Earth's magnetic field of 35° N., the magnetic low is on the north side of an associated magnetic high if the rocks are normally polarized, that is, if the remanent magnetization of source rocks is not in a direction significantly different from the direction of the Earth's present magnetic field. Thus, volcanic rift features, such as the southwest rift of Kilauea and the southwest rift of Mauna Loa, that are nearly parallel to the Earth's magnetic field are not as clearly indicated on the low-level magnetic map as are the rift features oriented nearly east-west, such as the east rifts of Kilauea and Mauna Loa Volcanoes. Malahoff and Wollard (1966) suggest that the surface geologic expressions of the southwest rifts of Kilauea and Mauna Loa Volcanoes are shallow crustal features, and thus were not expressed magnetically at the height of their earlier magnetic survey. Magnetic anomalies associated with the southwest rift zones are discontinuous (fig. 2) and probably reflect a history of volcanic activity followed by a period of stress readjustment through block slumping of the flanks of the volcanoes.

In order to better understand the configuration of magnetic source rocks of the linear magnetic features, the observed data along profile A-A' (fig. 2) in the Kilauea area were modelled using a potential-field inversion technique (Webring, 1985). The results (fig. 4) indicate that a vertical dike 2 km wide and having a susceptibility contrast of about one order of magnitude greater than the enclosing rocks would give a calculated magnetic anomaly closely approximating the observed field both in amplitude and shape. Note that the edges of the dike model lie nearly directly under the maxima and minima of the magnetic anomaly; thus, one can approximately locate the boundaries of the magnetic sources, especially in the east rift of the Kilauea area.

The magnetic high associated with the east rift of Kilauea follows closely the series of volcanic cones and craters; this correlation suggests volcanic activity along the southern edge of the rift zone. The dikes associated with the rift zone are widened by forceful intrusions from volcanic activity along the southern edge of the rift zone. The net effect of this volcanic activity is to force the south flank of Kilauea Volcano southward. Normal faulting along the Hilina fault system to the south of the Kilauea east rift zone also suggests a relative southward movement of the south flank of Kilauea Volcano. Swanson and others (1976) concluded, on the basis of seismic and geodetic evidence, that the south flank of Kilauea Volcano has been displaced upward and away from the rift zone by as much as several meters in the 20th century. The calculated model (fig. 4) of a 2-km-wide dike suggests there has been at least 2 km of southward movement of the south flank of Kilauea Volcano to accommodate this intruded mass.

The linear characteristic of the magnetic anomaly associated with the Kilauea east rift zone is broken by an interpreted transverse fault near Opihikoo on the southeastern shore of the island (marked T_1, fig. 2). Finch (1925) suggested that the location of pit craters along the rift zone may coincide with the intersection of the rift and secondary northeast- to southwest-trending fissures. East of the interpreted transverse fault zone, the east rift is offset to the north by about 1.5 km and continues eastward off the shore of the island at Cape Kumukahi. Zablocki (1977) outlined several self-potential (SP) anomalies in the interpreted transverse fault area, suggesting the SP anomalies are due to a geothermal convection system of groundwater overlying deep-seated hot zones. Apparent resistivity anomalies in the same general area lend additional support to existence of a fracture zone and, thus, are potential conductive zones associated with the geothermal convection system (Skokan, 1974).

An apparently reversely polarized dipole anomaly present over the Kapaho Crater area suggests an intrusive body about 2 km in diameter emplaced at a time when the Earth's magnetic field direction was the opposite direction to that of the present field. An alternative explanation was proposed by Norris (1976), who observed an intense magnetic high over Kapaho Crater, but did not observe the lower half of the magnetic dipole. He suggests that, "....if subsequent measurements were to show a proportionate magnetic low near the south rim, then it could be concluded that there is an anomalously non-magnetic body beneath Kapaho Crater." The amplitude of the reversed dipole anomaly is more than 1,800 nT. The wavelength of the observed anomaly is about 2 km. To determine whether or not the dipole anomaly is related to topography, a theoretical calculation was made (not shown) The results show that a magnetic anomaly detectable by a low-flying aircraft over the Kapoho crater would have a maximum amplitude of 300 nT where the aircraft would be unable to follow the topographic highs and lows over the cone and crater. The wavelength of such a spurious anomaly would be about 1 km, and the anomaly would show magnetic highs over the edges of the cone separated by a magnetic low over the crater. Thus, although the topographically induced magnetic anomaly has been superimposed upon the total observed anomaly, it does not adequately account for the dipole reversal. It seems unlikely that the apparently reversed magnetic dipole anomaly over Kapoho cone is due to reversely polarized intrusive rock because all of the Hawaiian rocks are younger than the last period of reversal of the Earth's magnetic field (Malahoff and Strange, 1965). Magnetic modelling (not shown) allowing for a nonmagnetic magma chamber, as suggested by Norris (1976), can account for the apparently reversed dipole anomaly observed over Kapoho cone.

Apparently reversed dipole anomalies are associated with Halemaumau and Kilauea Iki craters in the Kilauea volcanic center. Theoretical calculations of the magnetic effect of the topography suggest that only parts of these airborne anomalies are related to topography. Detailed magnetic measurements by Decker (1963) across Kilauea Iki crater indicate a positive magnetic anomaly associated with terrain on the north rim of the crater and a negative magnetic anomaly associated with terrain on the south rim. Terrain-caused magnetic anomalies have also been superimposed upon the magnetic anomalies of underlying rocks in the Kilauea Crater area. These terrain-caused anomalies are thought to form a part of the magnetic anomaly associated with the north rim but have little effect on the large-amplitude anomaly associated with south-southeast-trending intrusive dikes present along the eastern part of the crater. Northwest-trending linear magnetic anomalies crossing the eastern part of the Kilauea Crater area continue northwest, intersecting the east rift of Mauna Loa a few kilometers northeast of the summit, near the east Mauna Loa volcanic vent zone, as suggested by Malahoff and Wollard (1966, p. 285).

A moderate-amplitude (500 nT) magnetic high centered over the Thurston Lava Tube area, just east of Kilauea Iki crater, is part of an east- to northeast-trending linear dipole anomaly thought to be associated with a northeast extension of the southwest rift of Kilauea. This northeast-trending linear anomaly has a longer wavelength than that of the linear magnetic anomaly associated with the east rift of Kilauea; the difference in wavelength means, most likely, that the source rocks are at a much greater depth. Furthermore, the northeast-trending anomaly becomes a part of the magnetic expression of the primary east rift of Mauna Loa where it crosses the northern part of the Kilauea survey area.

The east rift of Mauna Loa is expressed in the aeromagnetic map (see also fig. 2) by linear dipole anomalies extending eastward from a few kilometers northeast of the summit to beyond the shore of the island, near Cape Kumukahi, where it joins the east rift of Kilauea in a submarine environment. The broad (5 km) long-wavelength, low-amplitude (500 nT) anomaly suggests that source rocks are at greater depth and probably wider than the presumed dike rocks associated with the east rift of Kilauea Volcano.

Two flight lines crossed Mokuaweoweo Crater at the summit of Mauna Loa. Along one line, nearly parallel to the west rim, is a marked magnetic low thought to be associated with terrain; along the second line, which crossed Mokuaweoweo Crater about a mile northeast of the first, there is no characteristic terrain anomaly, but rather a northeast-trending magnetic high thought to be associated with dike rocks forming a part of the east rift.

The southwest rift of Mauna Loa (map and fig. 2) is not as clearly defined by the magnetic data as are the features striking nearly normal to the direction of the Earth's present magnetic field. Several possible explanations exist to account for this lack of magnetic expression. As mentioned earlier, one prime consideration is the orientation of presumed intrusive rocks in reference to the direction of the Earth's magnetic field. The nature of the presumed intrusive dikes, that is, their width and implacement depth, may also be an important consideration. For example, there may have been less eastward movement of the east flank of Mauna Loa than has been observed on the southwest flank of Kilauea Volcano, in which case source rocks for a magnetic anomaly would be narrower or at a greater depth than in the Kilauea area. The interpreted axis of magnetic source rocks lies 2-3 km east of the active volcanic zone; this position indicates volcanic activity on the west and northwest edge of the rift. That the major bulk of the intrusive rock lies east of the active volcanic zone suggests either an east to southeast displacement of the southeast flank of Mauna Loa or migration of the active volcanic zone westward as suggested by Lipman (1980).

There is a prominent bulge in the Mauna Loa southwest rift that is reflected in the magnetic data (fig. 2). Northeast-southwest-trending magnetic source rocks dominate the upper part of the southwest rift. Surface evidence of the southwest rift zone and associated magnetic anomalies trend north-south on the southern end of the southwest rift zone. Buttressing of the southeast flank of Mauna Loa by the growing Kilauea Volcano has limited southeast gravitational slumping of that flank. Block slumping of the unbuttressed west flank of Mauna Loa (Normark and others, 1979) accompanied by westward migration of the active part of the rift zone accounts for the west bulge in the zone (Lipman, 1979).

SUMMARY AND CONCLUSION

Total-field aeromagnetic data presented on this map were acquired in a low-level, VLF magnetic survey of the rift systems associated with the Kilauea and Mauna Loa Volcanoes on the Island of Hawaii, Hawaii. The aeromagnetic map is characterized by normally polarized, linear dipole magnetic anomalies associated with presumed dikes emplaced along major rifts. The dikes are thought to comprise a composite of volcanic basalt rocks, particularly in the east rift of Kilauea, that have displaced the south flank of Kilauea Volcano. Circular dipole anomalies are associated with the major craters of Halemaumau, Kilauea, and Mokuaweoweo. These dipole anomalies are apparently reversely polarized and are thought to be related in part to topography. The reversely polarized magnetic dipole anomaly associated with Kapoho cone and crater has not been seriously affected by terrain-caused magnetic anomalies and is thought to be the magnetic expression of a nonmagnetic magma body within a magnetic terrane.

Dike rocks associated with the east rift of Kilauea are inferred to be shallow compared to similar magnetic source rocks associated with the east rift of Mauna Loa. Northeast-southwest-trending geologic features are not expressed as clearly in the magnetic data as are the east-west-trending features; this difference in expression is thought to be a geometry problem, that is, the northeast-southwest-trending features are nearly parallel to the Earth's present magnetic field.

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EXPLANATION

35000 — MAGNETIC CONTOURS--Showing total-intensity magnetic field of the Earth in nanoteslas. Hachured in areas of closed magnetic lows. Contour interval 100 nanoteslas (100 gammas)

— — — FLIGHT PATH--Showing location and spacing of data. Flight altitude 100-m (300-ft) mean terrain clearance. Flight-line spacing 1.6 km (1 mi) and 0.8 km (0.5 mi) in Kilauea area; 1.6 km (1 mi) in Mauna Loa area

SCALE 1:100 000

1 ½ 0 1 2 3 4 5 MILES

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

AEROMAGNETIC MAP OF THE RIFT SYSTEMS OF KILAUEA AND MAUNA LOA VOLCANOES, ISLAND OF HAWAII, HAWAII

By

Vincent J. Flanigan, Carl Long, Donald Rohret, and Pamela Mohr

1986

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