VOLCANISM IN HAWAII
Chapter 6

GEOLOGY OF THE SUMMIT OF LOIHI SUBMARINE VOLCANO

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ABSTRACT

Loihi submarine volcano is a seismically active seamount whose summit is at a water depth of 969 m (530 fathoms), 28 km (15 miles) southeast of the Island of Hawaii at 18°56′ N., 155°15.9′ E. Loihi is on the southernmost extension of the Kahoolawe-Hualalai-Mauna Loa volcanic line and probably marks the latest activity of the Hawaiian hot spot. The base of the volcanic edifice is 4,023 m (2,200 fathoms) below sea level. Loihi has formed through periodic volcanism along a northwest- to southeast-striking 31-km-long rift. High-resolution, shipboard hydrographic survey techniques supplemented by narrow, multibeam acoustic bottom surveys were followed by transponder-navigated bottom photography and ocean-floor dredge sampling. The combined data have produced a detailed picture of an emerging Pacific island. The summit of the volcano contains a calderalike depression 2.8 km wide and 3.7 km long with steep inner and outer walls. Within the depression, there are two pit craters; one is 0.6 km in diameter and 73 m deep, the other is 1.2 km in diameter and 146 m deep.

Shipboard and aeromagnetic studies show the presence of a 3,900-nT peak-to-peak normal bipole residual magnetic anomaly over its edifice. Superposed upon the normally polarized anomaly is a short wavelength, reversely polarized anomaly with peak-to-peak amplitude of 1,600 nT located directly over the summit of Loihi. Modeling of the reversely polarized anomaly suggests the source to be a nonmagnetic body, possibly a near-surface magma chamber below the summit of Loihi. Extensive bottom photography shows newly formed, glass-encrusted lava flows with pillow, sheet, lobate and aa forms erupted along the southeast slopes of the summit. The slopes of the volcano show evidence of recent, large-scale landslides that have scarred the volcano along its eastern and western slopes. Along the eastern edges of the summit depression, photographs show the presence of both hydrothermal activity and mineral precipitation with chimney forms similar to those mapped along the active rift systems of the East Pacific Rise and the Juan de Fuca Ridge. Orange to yellow iron-rich precipitates mark extensive hydrothermal vents around the central calderalike depression where water temperature anomalies in excess of several degrees Celsius have been detected. No exotic, hydrothermally associated, benthic animal communities have been detected in the present study. Photographic evidence suggests that forms of hydrothermal metallic precipitates found on Loihi may be similar to those found along the East Pacific Rise and that similar precipitates may be found at depths on other seamounts and volcanic islands.

INTRODUCTION

Loihi Seamount is a young (probably less than 0.5 Ma), active, submarine volcano on the southern extension of the Hawaiian hot spot (Jackson and others, 1972) along the Kahoolawe-Hualalai-Mauna Loa volcanic line; it is the youngest volcano in the Hawaiian Island chain and is the possible site for the next emerging island (fig. 6.1). The name Loihi, meaning long in Hawaiian, was first introduced by Emery (1955) to explain the elongate shape of the seamount. Loihi is seismically active, with shallow earthquake swarms that are distinct from the seismic activity of Kilauea (Klein, 1982), the nearest active volcano. A zone of deep earthquakes at a depth of 60 km between Kilauea, Loihi and Mauna Loa suggest a common deep source for the magma supply of the three volcanoes from the Hawaiian hot spot. Petrologic studies of basalt dredged from the volcanic edifice by Moore and others (1982) show these rocks to be glassy, tholeiitic pillow basalt, tholeiitic-alkalic transitional basalt, alkali basalt, and basanite. Most of the rocks sampled from the summit appear to be weakly vesicular, suggesting the possibility of mild explosive activity at the summit of Loihi (Moore and others, 1982). Extensive bottom photography and photointerpretation of surficial geology were performed by the author using the Woods Hole Oceanographic Institution's underwater camera system (ANGUS) deployed from the research vessel *Kana Keoki*. These data show the presence of fresh pillow lava, fresh sheet and lobate flows, and fresh aa and pahoehoe flows emerging from the summit of Loihi. Bottom transponder-controlled dredging (shipboard) of prospective hydrothermal deposit sites on the summit showed the presence of copper-enriched nontronite deposits (Malahoff and others, 1982). The nontronite was identified using bottom photography. The deposits were found to be associated with the freshest lava flows at several sites near the summit.

In order to map Loihi submarine volcano, detailed high-resolution bathymetric surveys were conducted over its summit by the National Oceanic and Atmospheric Administration (NOAA) vessels *Fairweather* and *Rainier*. The bathymetric surveys used shipboard traverses spaced 400 to 800 m apart. Navigation was by miniranger, with the network tied to the old Hawaiian datum. The details of the summit crater bathymetry were also mapped using the

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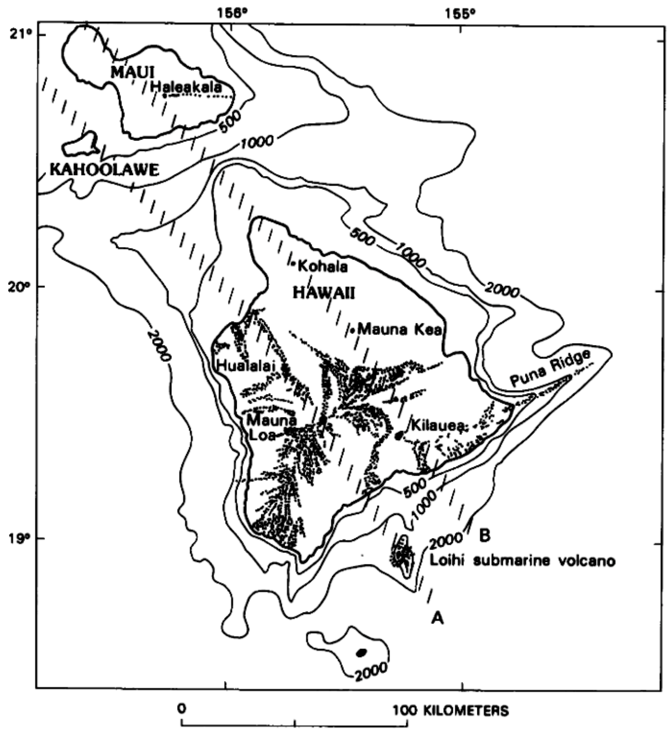


FIGURE 6.1.—Location of twin traces (hachures) of the Hawaiian hot spot showing Loihi submarine volcano at south end of Kahoolawe-Hualalai-Mauna Loa-Loihi trace (A), and the Haleakala-Kohala-Mauna Kea-Kilauea trace (B). Historical Hawaiian lava flows shown by dotted pattern. Bathymetric contours are in meters.

acoustic transponder and altimeter on the ANGUS photographic system. Bathymetric details of the whole volcanic edifice (see fig. 6.3) were determined through a U.S. Navy-conducted, high-resolution, narrow-beam, 64-beam Sonar Array Survey System (SASS) aboard the U.S. Navy (USN) ship *Hess*. All surveys were performed between 1978 and 1981. The depths for both the NOAA and the USN bathymetric surveys were plotted using fathoms as the depth unit. Airborne magnetic studies of Loihi were performed earlier by Malahoff and Woollard (1968, 1970) and were supplemented by shipboard magnetic traverses by vessels of the Hawaii Institute of Geophysics. This paper focuses on the surficial morphology and structure of Loihi as an example of the early stages of the structural development of a Hawaiian island as a submarine volcano.

ACKNOWLEDGMENTS

The research described in this paper was supported by funding from the National Ocean Survey (NOS) of the National Oceanic and Atmospheric Administration (NOAA). The United States Navy provided ship time aboard the USN ship *Hess* to conduct the multibeam, narrow-beam surveys over the flanks of Loihi. The bottom photographic surveys were performed by the ANGUS group of the Woods Hole Oceanographic Institution in October 1980 aboard the University of Hawaii's research vessel *Kana Keoki*. It was through the dedication and professionalism of the ANGUS team that such excellent photographic data were obtained during adverse weather conditions. I would like to thank Dr. Frisbee J. Campbell of the Hawaii Institute of Geophysics, University of Hawaii, and Captain William King of the research vessel *Kana Keoki* for their assistance in organizing the shipboard operations, and also the commanding officers of the NOAA ships *Rainier* and *Fairweather* for the excellent hydrographic coverage obtained over the summit of Loihi. I am grateful for the assistance and discussions offered during the cruise by Dr. Stephen Hammond and Dr. Robin Holcomb, for critical reviews of this paper by Dr. Gary McMurtry, and also for the help of Ms. Cheryl Komenaka in the preparation and compilation of the manuscript.

MORPHOLOGY OF THE VOLCANIC EDIFICE

Loihi is on the eastern flank of the southern extension of Mauna Loa volcano (fig. 6.1). Its northern base is 1,900 m below sea level, whereas the southern base is 4,755 m below sea level, showing that the edifice of Loihi was built on an original submarine slope of about 5°. The volcano apparently grows through continued volcanism, not only from a caldera or summit craters, but also from an elongate rift system consisting of a 17-km-long southern rift limb and a 7-km-long northern rift limb (fig. 6.2). The Loihi rift and crater system is not unlike those for the summits of the neighboring Mauna Loa and Kilauea Volcanoes.

The steepness of the southwestern and northeastern slopes of the volcano (35° to 40° between the water depths of 1,830 and 3,290 m) and the presence of armchairlike indentations into the edifice (at 155°14′ W., 18°47.5′ N., at 155°17.5′ W., 18°52.5′ N. and at 155°15′ W., 18°57.5′ N.) suggest that extensive erosion in the form of downslope mass wasting has occurred contemporaneously with the growth of the edifice by submarine volcanism. Bottom photographs of the upper flanks of Loihi show the development of talus slopes through the breakup of pillow basalt and sheet and lobate flows. The sheet and lobate flows frequently exhibit the photographic characteristics of pahoehoe and aa lava at the summit. The shaded areas in figure 6.2 indicate sites of talus slope and downslope mass wasting as interpreted from the study of bottom photography and bathymetry. Examination of the bathymetric data does not show the presence of any extensive flank cones on Loihi. This evidence, however, does not preclude the possible presence of flank fissures. The process of talus generation and downslope mass wasting appears to be steady and extensive. Therefore, the upward growth of the volcano is dependent upon a constant source of extrusive magma from the summit crater and the upper rift zones.

The detailed bathymetric map of the Loihi summit (fig. 6.3) was prepared from the total bathymetric data base, including the NOAA hydrographic survey, the Woods Hole Oceanographic Institution ANGUS camera data, and the USN SASS surveys. The combined bathymetric data suggest that the summit of Loihi has an oval configuration with the long axis parallel to the rift zone. A summit depression about 2,800 m wide and 3,700 m long appears

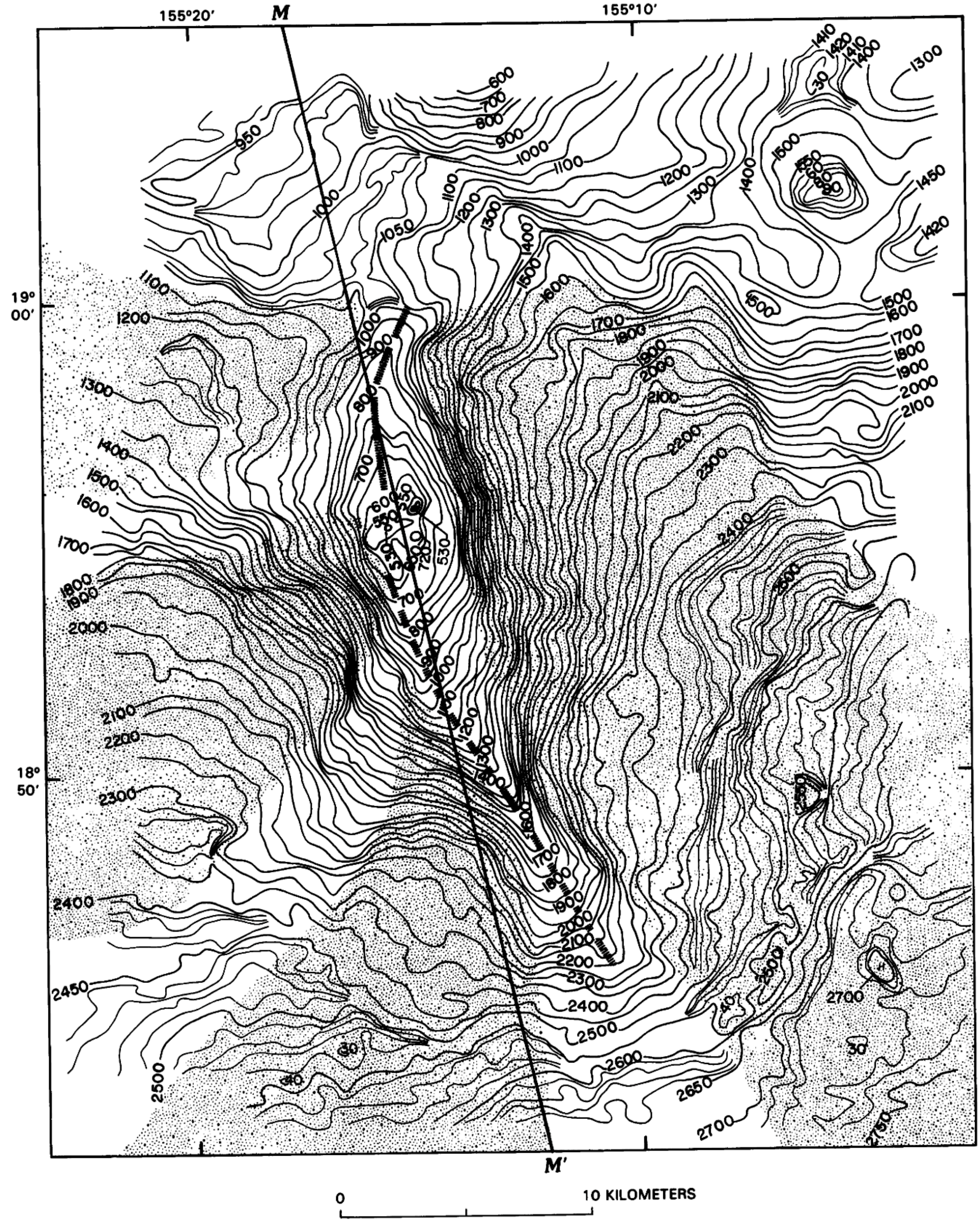


FIGURE 6.2.—Bathymetric map of Loihi, constructed from narrow-beam, multibeam surveys carried out aboard the U.S. Navy ship *Hess*. Water depth in fathoms (1 fathom = 1.83 m). Dotted pattern shows flanks of volcano that may have been subjected to mass wasting and talus formation. Heavy hachured line indicates the location of north and southeast rift zones of Loihi. Profile *M–M'* refers to figure 6.6.

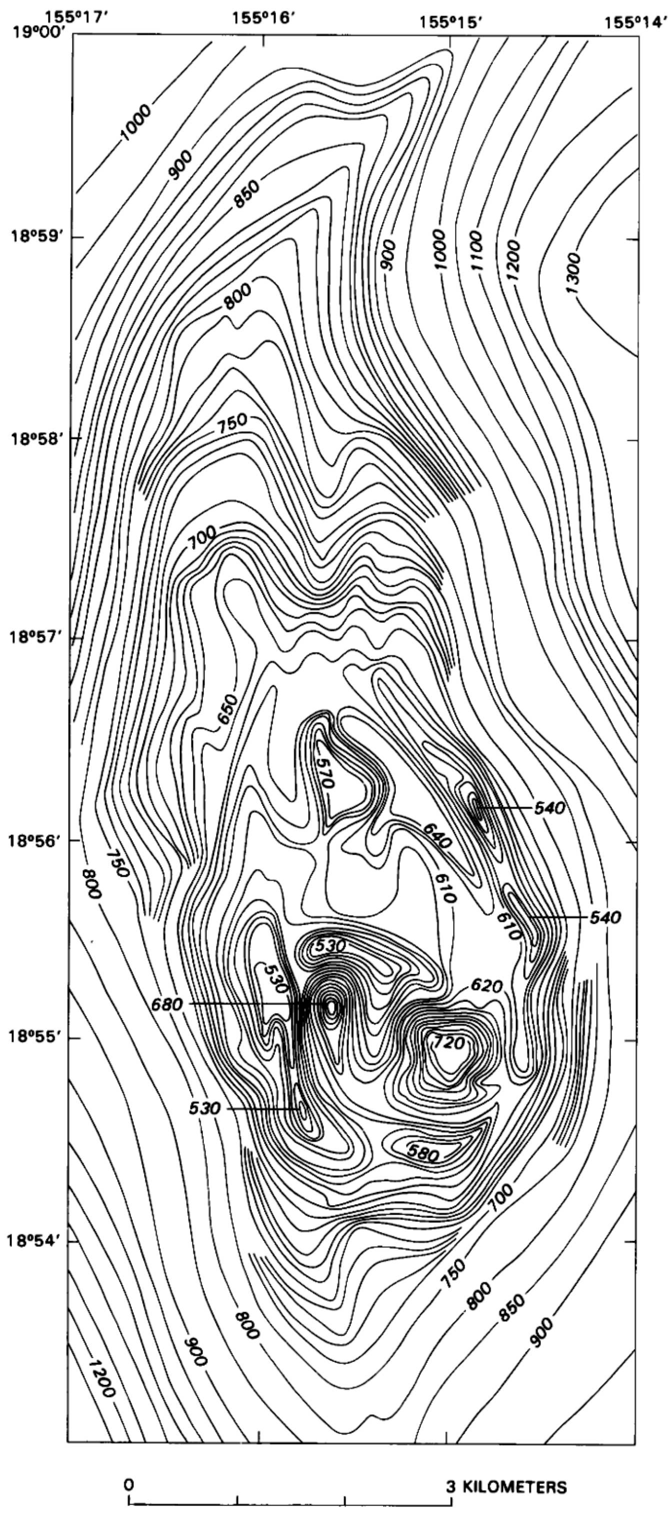


FIGURE 6.3.—Detailed bathymetric map in fathoms of summit area of Loihi, drawn from narrow-beam, multibeam surveys by the U.S. Navy ship *Hess* and narrow-beam surveys over summit area by the NOAA ships *Fairweather* and *Rainier.* Contour interval: 10 fathoms at summit and 50 fathoms on flanks.

to be structurally offset to the east of the north-south rift system. This depression, possibly a summit caldera, is approximately 128 m deep from rim to floor. The shallowest point along the rim is 969 m below sea level. Two pit craters within the caldera-like depression are 73 and 146 m deep. The Loihi summit depression may be a young caldera similar in its geologic structure to that of Kilauea caldera. Macdonald and Abbott (1970) suggest that the development of a caldera in a developing Hawaiian volcano, such as Kilauea, could begin early in the life of the volcanic edifice, which could be the case for young submarine volcanoes such as Loihi.

The geographic proximity of Kilauea and Loihi and the common deep magmatic source (Klein, 1982) suggest that both Kilauea and Loihi are in their early stages of edifice development. Indeed, the location and size of Loihi indicate that it may, in fact, be the youngest Hawaiian volcano. Therefore, the Loihi summit may be undergoing periods of swelling and shrinking as a result of shallow magmatic injection and removal through flank eruptions, similar to those that occur at Kilauea. Such magmatic processes could result in the formation of a subsidence caldera on Loihi. The summit depression of Loihi is surrounded by an oval ring of bathymetric highs (fig. 6.3) that could mark the outer rim of the caldera. Alternatively, the bathymetric highs could also mark a ring of individual volcanic cones or vents on the summit. A physiographic diagram of the summit of Loihi, based upon the high-resolution bathymetric data, was drawn by the author (fig. 6.4) to show the structural relation between the location of the summit depression and the flank rift zones (Malahoff and others, 1982). As in the case of Kilauea, the two pit craters appear to have been formed on the floor of the Loihi summit depression. The structural setting of the summit depression, based upon analyses of the bathymetric data, suggests an offset between the north flank and south flank rifts at the summit of Loihi.

STRUCTURE OF THE LOIHI EDIFICE

Studies of earthquake distribution beneath the summits of Mauna Loa, Kilauea and Loihi by Klein (1982) indicate that between the surface of the Island of Hawaii and a depth of about 40 km these volcanoes have separate volcanic conduits. Below that depth the earthquake hypocenters form a more common zone. The Hawaiian hot spot is interpreted by Klein (1982) to be at a depth of 60 km between and beneath the three volcanoes. Magmatic activity at the three volcanic sites can be explained by a dynamic model of an idealized Hawaiian volcano developed by Eaton and Murata (1960) and Eaton (1962), and by Klein (1982) from interpretation of seismic events associated with Kilauea and Loihi. This model shows the location of a magma reservoir to be 2 to 3 km beneath the summit caldera. This magma reservoir is refilled with magma from the 60-km-deep hot spot source. In this model, flank eruptions are followed by the partial emptying of the reservoir and, in the case of large flank eruptions, by the formation of pit craters at the summit. Growth of the volcanic edifice occurs as surface lava flows emanate from the summit and the flank rifts, and the intrusion of magma forms dike complexes within the rift zones. The source for these magmatic events in the model appears to be a summit magma reservoir. It is assumed in this paper that the magmatic plumbing of Loihi is similar to that of the model.

Magnetic anomalies have been used in the past to study the size and shape of dike complexes within active and extinct volcanic centers of the Hawaiian Islands (Malahoff and Woollard 1968, 1970). Aeromagnetic studies of the active volcanoes along the Islands of Vanuatu (Malahoff 1970) showed the superposition of short-wavelength, reversed magnetic anomalies on the normally magnetized bipole anomalies located over the edifices of the volcanoes. Models based upon the wavelength of the observed magnetic anomaly, the magnetization of the volcanic edifice, and the contained dike complex were used by Malahoff and Woollard (1968, 1971) to construct calculated anomalies that were matched to those observed above the volcanic centers of Hawaii. Johnson and Malahoff (1971) conducted magnetic anomaly studies over Macdonald submarine volcano, at the southern end of the Austral Island chain. Macdonald Volcano marks the active volcanic center of the Austral Islands hot spot. A 500-nanotesla (nT), reversely polarized magnetic anomaly is superposed upon the normally polarized bipole of the volcano. In the aeromagnetic study of the Vanuatu volcanoes, Malahoff (1970) detected a similar reversely magnetized short-wavelength anomaly over the active Ambrym Volcano and interpreted that anomaly to reflect the presence of rocks having temperatures above the Curie point, approximately 578 °C for magnetite (Nagata, 1961), within the edifice of the volcano. Johnson and Malahoff (1971) interpreted the origin of the observed, reversely polarized, secondary magnetic anomaly above Macdonald Volcano to also be due to the presence of volcanic rocks heated above the Curie point within the edifice of the volcano, thus possibly marking the site of a magma reservoir.

The compilation of the residual magnetic anomaly data over the southern end of the Hawaiian Island chain is depicted in figure 6.5. All volcanoes on the Island of Hawaii show the presence of normally polarized, high-amplitude magnetic anomalies, such as 750 nT for Kohala Volcano, 1,250 nT for the east rift zone of Kilauea, 900 nT for Mauna Kea, 100 nT for Kilauea, 600 nT for Hualalai, 800 nT for Mauna Loa and 1,100 nT for Loihi. The high-amplitude anomalies are formed by the combined magnetic effects of the volcanic edifice and the intrusive dike systems within the edifice. The aeromagnetic profiles over Loihi were flown at an altitude of 2,800 m. A northwest- to southeast-oriented magnetic anomaly profile was also taken aboard the research vessel *Kana Keoki* across the summit of Loihi and approximately above the long axis of the edifice (profile $M-M'$, fig. 6.2). Figure 6.6 illustrates the wavelength and amplitude of the residual magnetic anomaly of this profile. At sea level, the total amplitude of the normally polarized, residual magnetic anomaly above Loihi is 3,900 nT (peak-to-peak). It is assumed that the normal polarity of the residual magnetic anomaly is due to the presence of flow and dike basalt younger than 0.7 Ma, the age of the present normal magnetic polarity epoch (LaBrecque and others, 1977).

It is interesting to note that superposed upon the normally polarized magnetic bipole anomaly is a reversely magnetized bipole anomaly with a peak-to-peak amplitude of 1,600 nT. As with

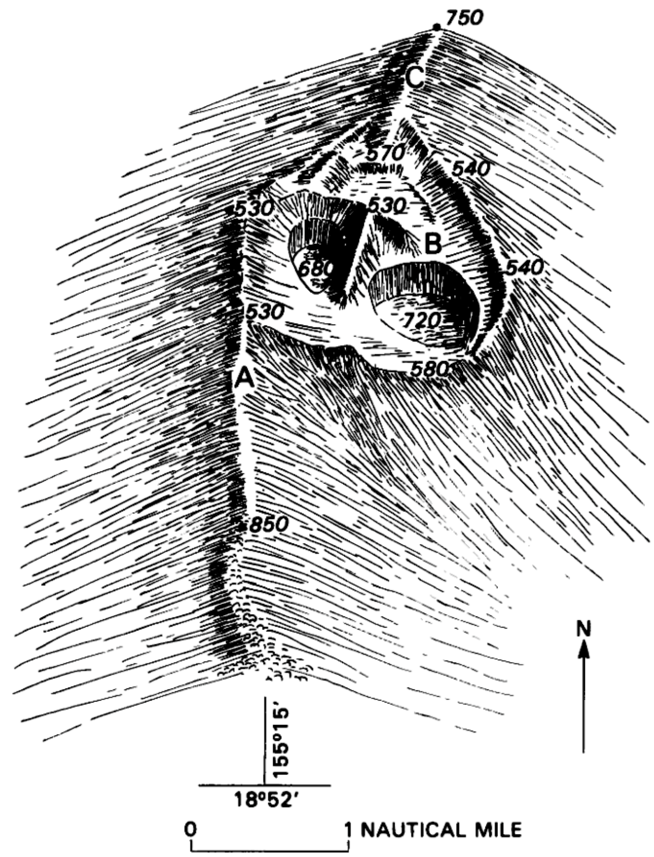


FIGURE 6.4.—Perspective physiographic drawing of summit of Loihi, constructed from bathymetric data base shown in figure 6.3. Spot depths in fathoms. Principal physiographic features: A, southeast flank rift; B, summit caldera with pit craters; C, north flank rift.

similar studies of secondary bipole residual magnetic anomalies observed over active volcanoes (Malahoff, 1970; Johnson and Malahoff, 1971), the interpretation of the observed magnetic anomaly is based upon several speculative source models. Using a two-dimensional model technique (Heirtzler and others, 1962) and the assumption of only a terrain effect for the normally magnetized bipole anomaly, a bulk rock magnetization of 75×10^{-3} emu was required to construct a calculated anomaly for the edifice of Loihi that would match the observed bipole anomaly. The assumed magnetization of 75×10^{-3} emu for the volcanic edifice of Loihi falls within the range of 20×10^{-3} emu to 150×10^{-3} emu measured by Johnson and Clague (1981) for the magnetization of samples recovered by rock dredging from Loihi. The observed anomaly can also be matched with a calculated anomaly based upon a terrain model with an associated dike complex having a magnetization contrast of 15×10^{-3} emu, extending to a depth of 40 km below the summit. In both of these terrain-effect calculations, however, the reversely magnetized, superposed bipole anomaly (fig. 6.6) is difficult to account for. As a speculation, the reversely polarized anomaly was modeled by using a nonmagnetic block (rocks heated

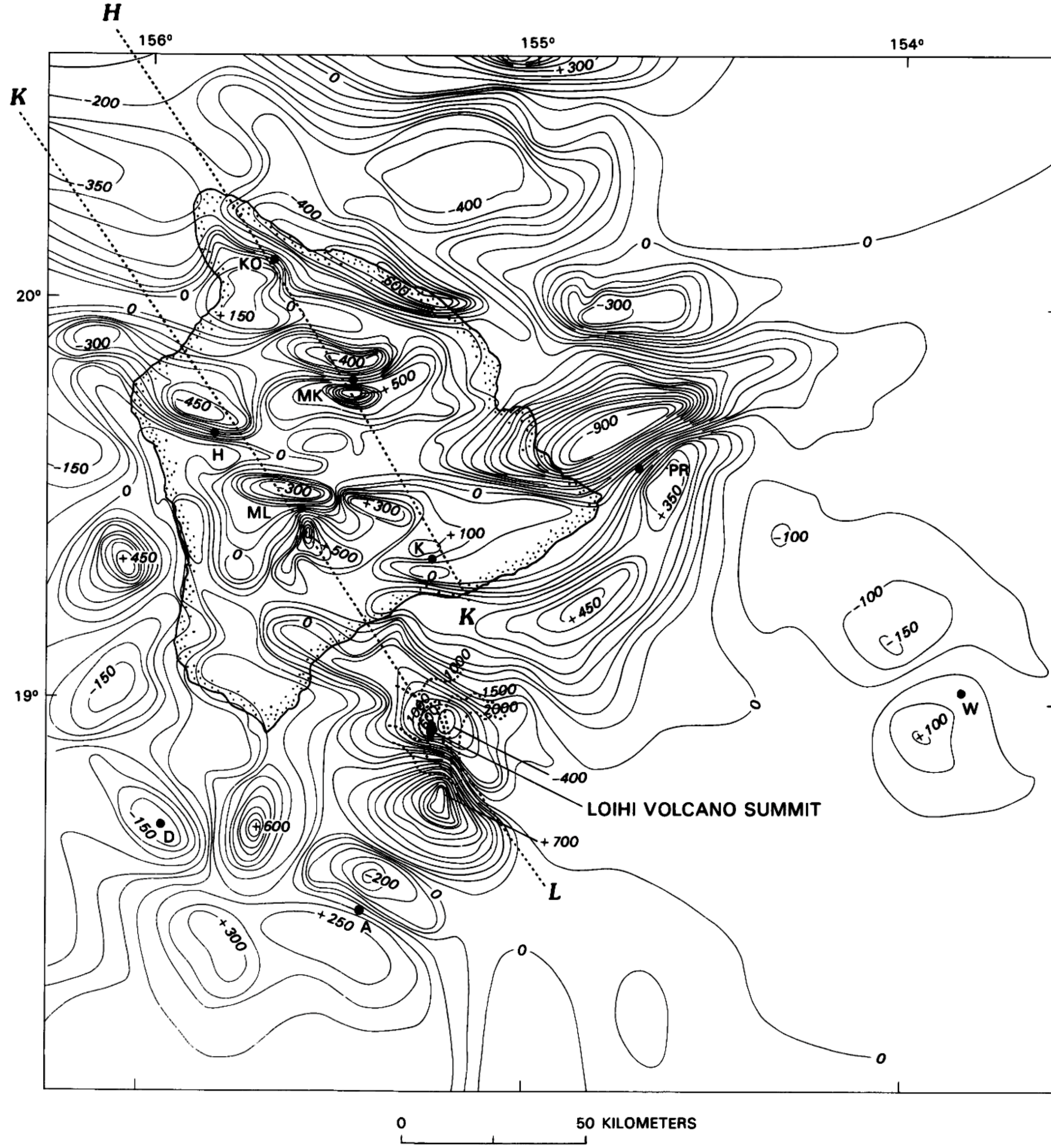


FIGURE 6.5.—Residual total-force magnetic anomaly map of Island of Hawaii and surrounding ocean areas; intensity in nanoteslas (nT). Data obtained from aeromagnetic flights, altitude 2,000 m above sea level over ocean and lower slopes of island. Flight altitude 3,000 m above Mauna Kea (MK) and Mauna Loa (ML). Other volcanic centers: KO, Kohala; H, Hualalai; K, Kilauea; PR, Puna Ridge; W, Wini Seamount; A, Apuupuu Seamount; D, Day Seamount. Dotted contour lines over Loihi summit show general bathymetry in fathoms. Haleakala-Mauna Kea-Kilauea trace of hot spot shown by line $H-K$; the Kahoolawe-Hualalai-Mauna Loa-Loihi trace shown by line $K-L$. Aeromagnetic data from Malahoff and Woollard (1970).

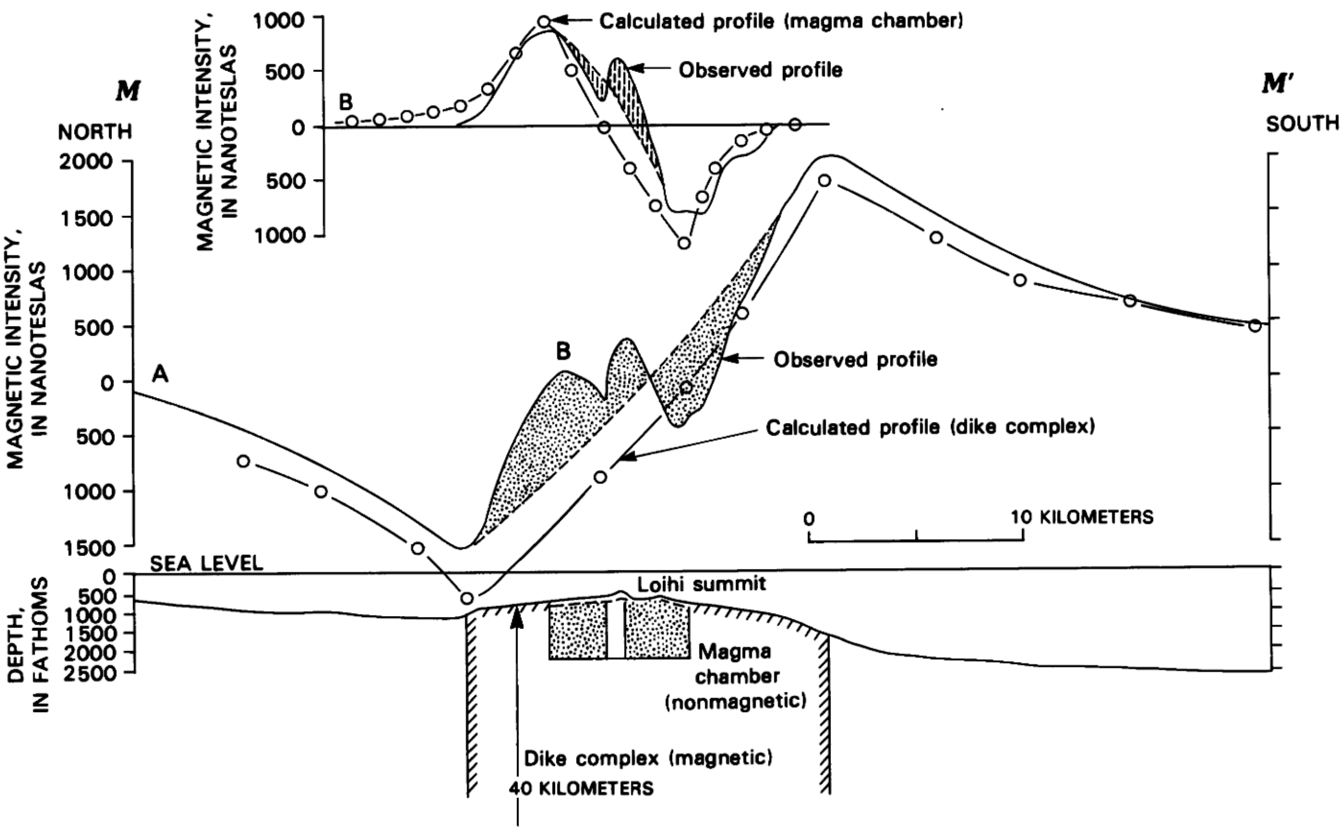


FIGURE 6.6.—Residual total-force magnetic-anomaly profile, M–M' (see location on fig. 6.2), observed at sea level above flank rifts and summit of Loihi. Magnetic intensity in nanoteslas (nT). Principal components of profile: profile A, normally polarized residual total-force magnetic anomaly; profile B, stippled area representing reversely magnetized section along profile A. Profile B also shown in upper diagram in form of residual anomaly subtracted from profile A. Calculated profile, lower diagram, based on model of surficial terrain effect and a magnetic dike complex, with assumed magnetization contrast of 15×10^{-3} emu extending to depth of 40 km. Calculated profile, upper diagram, is based on model of nonmagnetic magma chamber within Loihi edifice. Dashed area (upper diagram) represents normally polarized anomaly segment within profile B assumed to reflect small magnetic body within magma chamber.

above the Curie point) 7 km wide, possibly 3 km in vertical extent, located beneath the surface of the Loihi summit and divided in half by a vertical rock body less than 1 km wide having temperatures below the Curie point (normally polarized; fig. 6.6). This speculative interpretation of the observed residual magnetic anomaly profile over Loihi is based upon one of a number of models and suggests the presence of a heated rock body within the edifice of Loihi Volcano. This rock body could be a shallow summit magma reservoir that, as at Kilauea, may be structurally expressed at the summit by the presence of a caldera and pit craters.

NEOVOLCANIC ZONES OF THE LOIHI SUMMIT

The geologic interpretation of bottom photographic data (fig. 6.7) from the summit of Loihi shows a broad range of lava types and vents present on the summit. The photographic data were obtained using the Woods Hole Oceanographic Institution's ANGUS camera system, with a bottom-transponder navigation network and tow altitudes of 5 to 20 m above the ocean floor. The data were visually examined for the presence of geologic features such as fresh or broken pillow lava, lobate, sheet, aa and pahoehoe lava flows, talus, exposed dike systems, smooth or rippled sediment, visible structural features such as faults and fissures, and evidence of hydrothermal activity, such as yellow, orange or green precipitates (that is, nontronite; Malahoff and others, 1982), or the presence of hydrothermal chimneys. Photointerpretation techniques used in this study were similar to those used by Ballard and others (1979, 1982) and Crane and Ballard (1980) for ANGUS photographic data taken over the neovolcanic zone of the Galapagos Rift. Photographs were analyzed, frame by frame, and condensed into the interpretative geologic map shown in figure 6.7. The most interesting observation derived from the study of the photographic data over the Loihi summit is the relatively small area covered by fresh lava flows. The

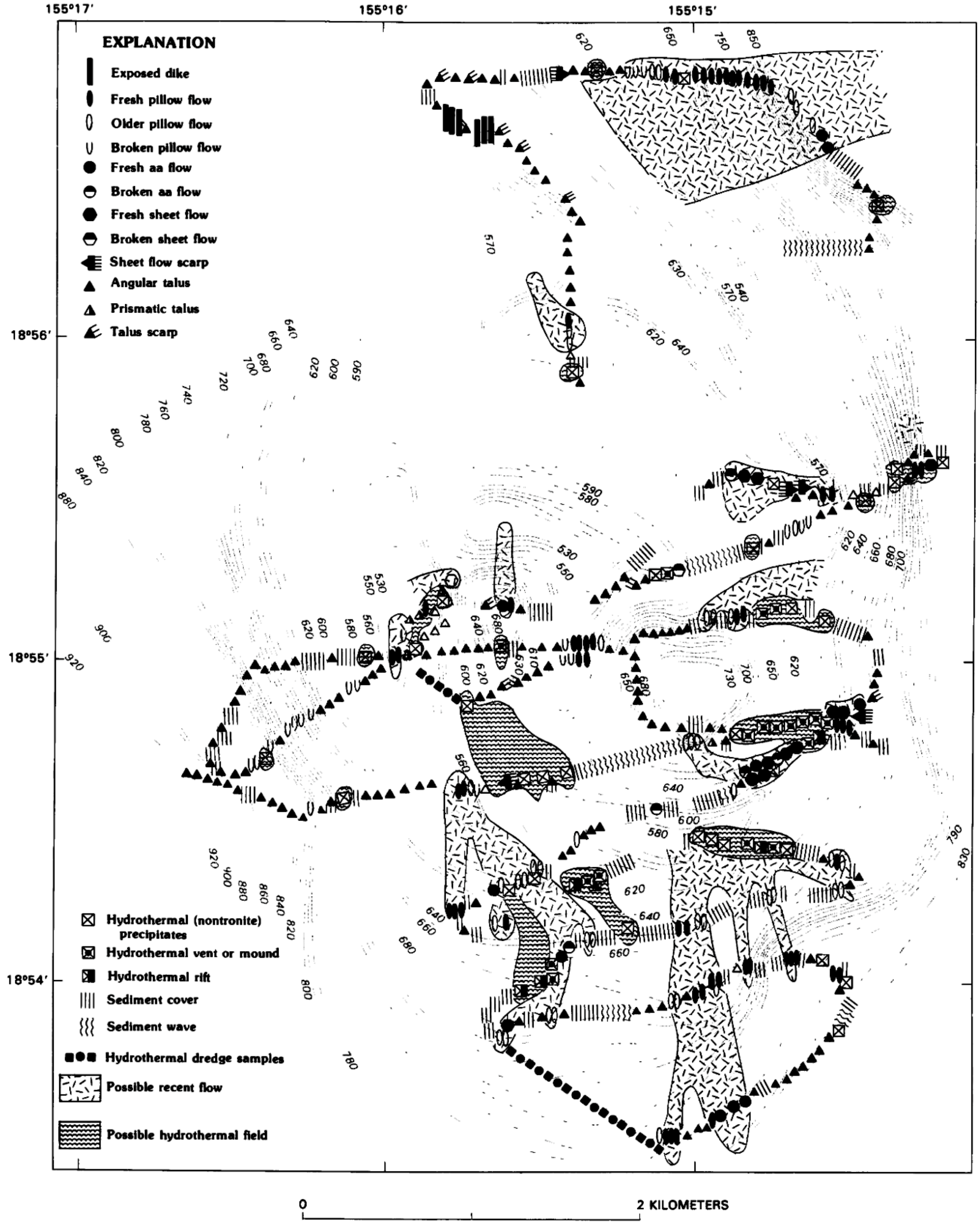
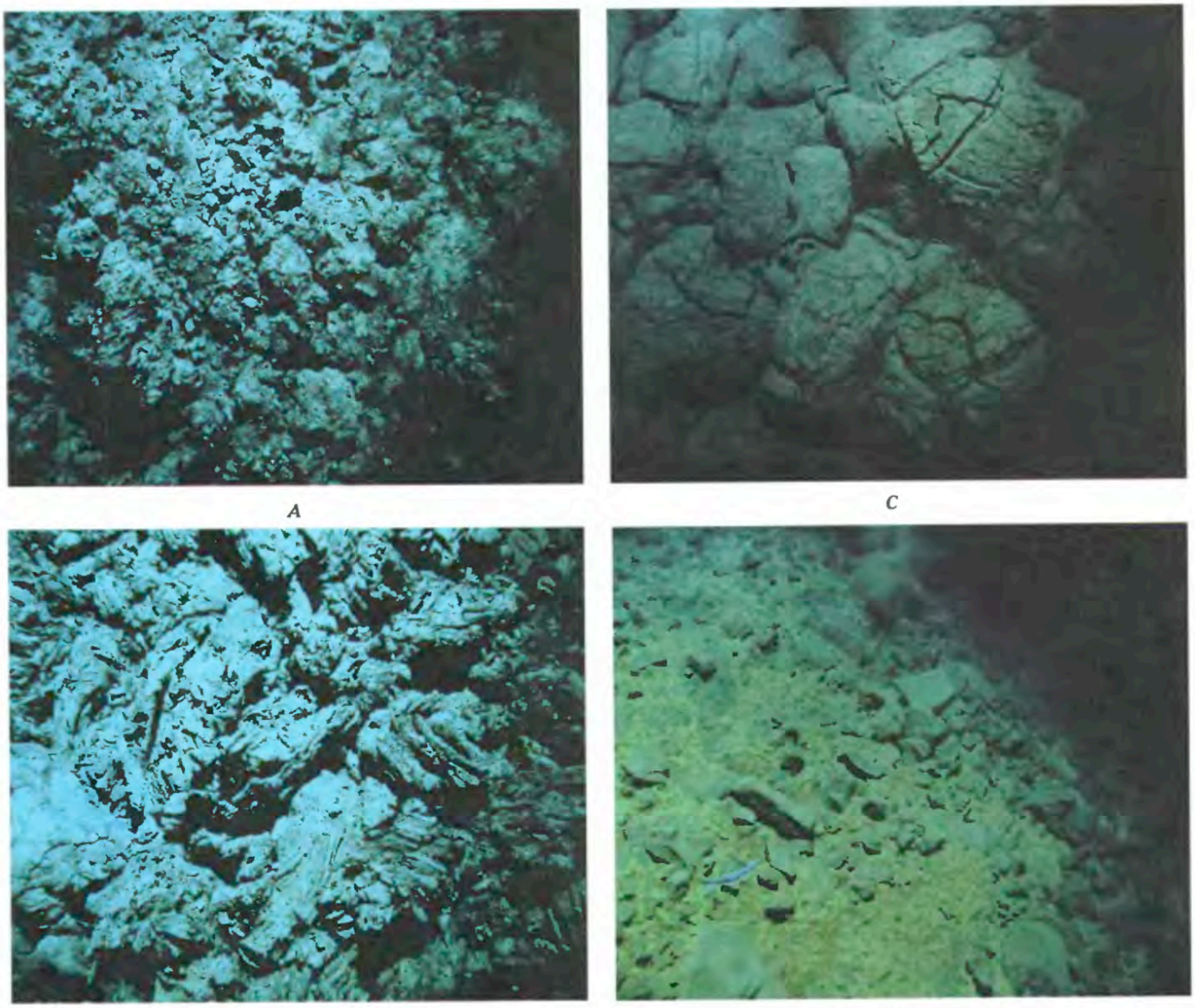


FIGURE 6.7.—Interpretive geologic map of Loihi summit area. Geologic symbols are drawn along tracklines of ANGUS camera system. Geologic data are superposed upon high-resolution bathymetric map (contour interval, 10 fathoms).



A C B D

FIGURE 6.8.—Ocean-floor photographs of aa and pillow flows and talus, Loihi summit. ***A***, Blocky, fresh transitional pahoehoe to aa flow, south caldera rim; photocoverage 14 by 22 m, location at 155°14.9′ W., 18°53.7′ N. ***B***, Blocky, fresh transitional from pahoehoe to aa flow; photocoverage 7 by 11 m; location same as in 8*A*. ***C***, Fresh pillow basalt, northeast rim of Loihi caldera; photocoverage 10 by 14 m; location at 155°14.9′ W., 18°56.8′ N. ***D***,Talus along western inner margin of the summit depression; photocoverage 10 by 14 m. Yellow to orange hydrothermal nontronite covers much of central area of photograph; location at 155°15.95′ W., 18°55′ N.

freshest lava flows, those with high photoreflectivity and no visible sign of sediment coverage (fig. 6.8*A*, *B*), were found to originate from volcanic centers along the southern edge of the Loihi summit depression. The two longest lava flows appear to extend a maximum distance of 1,800 m from their sources, which are at water depths of 970 to 1,060 m. The photographic data suggest that these lava flows consist largely of pillow (fig. 6.8*C*) and lobate flows at the vent sites and transform into lava types similar to aa or broken sheet flows (fig. 6.8*A*, 6.9*B*) downslope from the vent site.

The steeper slopes of Loihi outside the summit depression are covered by talus, as are the steeper, inside slopes of the pit craters (fig. 6.9*B*). The floors of the two pit craters appear to be covered by sediment. Talus appears to be common in the photographic data. Sheet flows, similar in their photographic appearance to those observed by Ballard and others (1979, 1982) over the Galapagos Ridge, were photographed at several sites at the northeastern rim of the summit depression (fig. 6.9*A*). Sheet flows appear to form at the site of submarine volcanic eruptions where higher magmatic volumes and higher extrusion temperatures may have occurred. These flows occupy areas of the Loihi summit that are less than a few thousand square meters in area. They appear to undergo mechanical breakup soon after extrusion, with the downslope mass wasting resulting in the formation of talus (fig. 6.9*B*). Downslope mass-wasting talus development has apparently been extensive enough to expose the

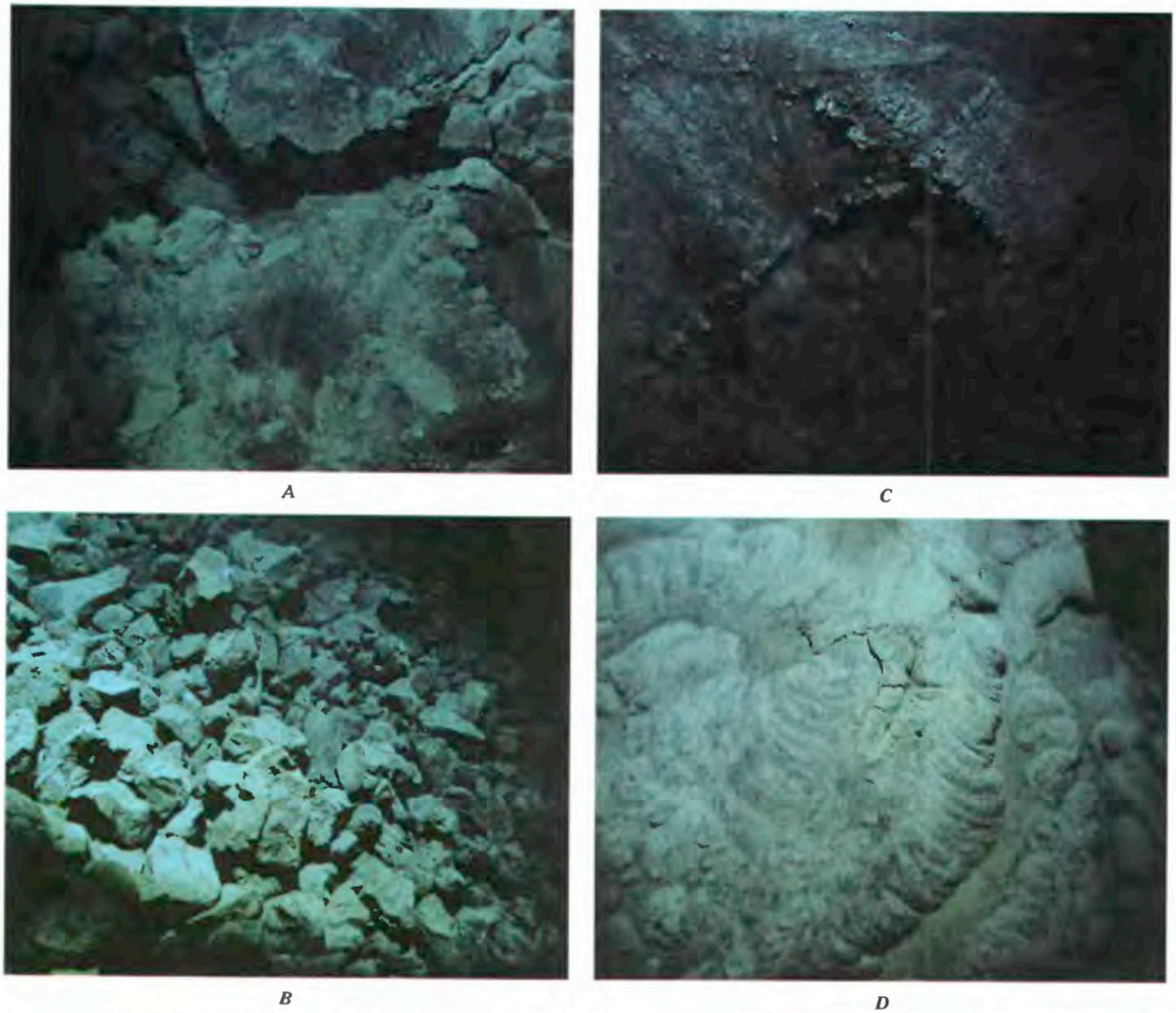


FIGURE 6.9.—Ocean-floor photographs of fresh sheet flows, broken sheet flows, exposed dikes, and lobate flows, Loihi summit. ***A***, Fresh sheet flow, showing initial stages of mechanical breakup; photocoverage 13 by 20 m; location at 155°14.8′ W., 18°54.65′ N. ***B***, Talus derived from broken sheet flow; photocoverage 10 by 14 m; location same as in 9*A*. ***C***, Exposed dike rocks, north rim Loihi caldera; photocoverage 24 by 36 m; location at 155°15.7′ W., 18°50.7′ N. ***D***, Ponded lobate and pillow flows; photocoverage 17 by 25 m, location at 155°15.4′ W., 18°56′ N.

underlying dike structure (fig. 6.9*C*) at the northern edge of the summit depression. Ponded lava is also observed (fig. 6.9*D*). Incipient lobate flows appear to have developed in association with the lateral lava drainage out of the lava ponds, that formed in flat-lying areas of the summit depression.

The slopes of the two pit craters within the summit depression appear to be covered by talus. Rippled sediment and talus cover large areas of the basaltic floor of the summit depression and the pit craters. Lava flows with the freshest appearance in the photographs are on the southern rim of the summit depression. The lava appears to have erupted from vents on the local highs that have the appearance of cones.

Extensive patches of hydrothermally precipitated yellow, red or green iron oxide and nontronite (Malahoff and others, 1982; DeCarlo and others, 1983) cover areas of the talus slopes (fig. 6.8*D*) and also form fields of individual chimneys 0.5 to 2.0 m high (fig. 6.10). Transponder-controlled shipboard dredging of two of the hydrothermal vent sites along the southern edge of the summit depression produced samples of yellow-brown goethite and nontronite, similar in composition to the iron-rich montmorillonite-nontronite recovered from the Red Sea Rift, the East Pacific Rise and the Galapagos hydrothermal mounds (Malahoff and others, 1982), as well as from the caldera of Axial Volcano on the Juan de Fuca Ridge (McMurtry and others, 1984). The shape and size of

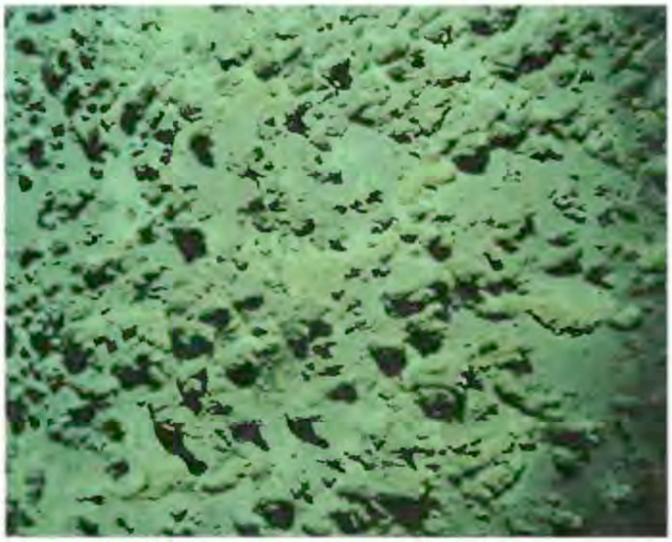


FIGURE 6.10.—Ocean-floor photograph of hydrothermal field, southeast edge, Loihi summit depression. Hydrothermal chimneys 0.5 to 2 m high. Dark areas to side of chimneys are shadows cast by camera strobe lights; photocoverage 14 by 22 m, location at 155°14.75′ W., 18°54.45′ N.

the low temperature hydrothermal chimneys of Axial caldera are similar to those photographed by the ANGUS system over Loihi. More than 100 chimneys can be counted in the photograph of figure 6.10, which covers an area of approximately 22 by 14 m.

The hydrothermal vent fields on the summit of Loihi are as long as 600 m. Malahoff and others (1982) measured water temperature anomalies of greater than 1 °C at a water depth of 10 m above the ocean floor where the nontronite-iron oxide deposits are situated, suggesting an extrapolated temperature of about 30 °C at the vent sites on the ocean floor. Most of the hydrothermal fields mapped in this study are characterized by the presence of reddish-yellow hydrothermal precipitates deposited on the surface of sediments (fig. 6.10), on talus (fig. 6.8*D*) or along cracks and fissures of sheet flows. All the hydrothermal vents with identifiable chimneys mapped in this study are adjacent to fresh lava flows (fig. 6.7). The association between fresh lava flows, visible hydrothermal vent fields and water temperature anomalies is common at midocean ridge-crest sites (Haymon and Kastner, 1980; Lonsdale and others, 1980; Ballard and others, 1981; Bäcker and others, 1985; Hekinian and Fouquet, 1985) and ridge-crest submarine volcanoes such as Axial (Malahoff and others, 1984; McMurtry and others, 1984) and along off-ridge seamounts such as the Red and Green Seamounts off the East Pacific Rise at 20°50′ N. (Lonsdale and others, 1982). At the active vent sites of Axial caldera, outer zones of disaggregated nontronite precipitates are found beyond the inner zone of sulfide precipitation and the middle zone of nontronite chimneys (McMurtry and others, 1984; Arquit and others, 1985). A similar outer zone, consisting of isolated patches of nontronite deposits, is found precipitated on the upper talus-covered slopes of Loihi, and thus probably marks the outer zones of Loihi hydrothermal fields.

The depth of the hydrothermal vent fields on Loihi mapped in this study ranges from a shallow point of 1,043 m below sea level at the southern rim of the summit depression to 1,500 m below sea level along the flanks of Loihi. Other hydrothermal vent sites may be present along the north flank and south flank rifts of Loihi.

To date, no high-temperature hydrothermal minerals, such as polymetallic sulfides, have been sampled during this or other shipboard rock-dredging expeditions on Loihi (Moore and others, 1982; DeCarlo and others, 1983), although it is possible that polymetallic sulfides may have been precipitated as chimneys (observed in the bottom photographs) or beneath the surface of Loihi (DeCarlo and others, 1983). High-temperature water anomalies were not detected over the summit of Loihi during the current studies, and no evidence for hydrothermal vent macro-organisms, such as worms or clams, has been observed in the current photographic data set taken over the summit of Loihi.

DISCUSSION

Loihi submarine volcano is a young Hawaiian volcano that is 969 m below sea level at the southern end of the Kahoolawe-Hualalai-Mauna Loa limb of the Hawaiian hot spot trace. The comprehensive bathymetric, photographic, geologic, and magnetic studies conducted over the Loihi summit show the volcano has structural similarities to the young subaerial volcanoes of Hawaii. The 2.8-km-wide summit depression, with a rim depth of 969 m below sea level and a floor depth of 1,134 m below sea level could represent the initial stages of submarine caldera development. Two pit craters within the summit depression are similar in their structural setting to craters on the summit of Kilauea Volcano. The summit depression of Loihi appears to be at the intersection of two flank rifts. Most of the volcanic extrusions that have built the edifice of Loihi probably erupted from the two flank rifts and from summit vents, thus giving Loihi its elongate shape. Although seismic studies show that the magma supply for Mauna Loa, Kilauea and Loihi originates from a common source (probably the Hawaiian hot spot) at a depth of 60 km or more beneath the surface, all three volcanoes apparently have individual conduits and seismic further showing that the magmatic cycles of the three volcanoes are largely independent of each other. A pronounced 3,900-nT peak-to-peak residual total-force magnetic anomaly is also observed over the edifice of Loihi. Within the configuration of this normally polarized, bipole anomaly, a shorter wavelength anomaly of amplitude 1,600 nT and having a reversed polarization is observed. The configuration of reversed polarization within a normally polarized magnetic anomaly profile has been observed over other active subaerial and submarine volcanoes. A speculative interpretation of the residual total-force magnetic anomaly observed over Loihi suggests the presence of a heated rock body or magma source, with temperatures above 578 °C, 7 km wide and 3 km thick located within the edifice.

Visual examination of the photographic data reveals the most common rock type to be volcanic talus. Ten fresh lava flows were mapped in this study with their vent sources traced to volcanic mounds located in and around the summit depression. The most extensively mapped lava flows with the freshest appearance are about 2 km long and are along the southern rim of the depression; this lava appears to have erupted from 100- to 150-meter-high volcanic mounds. The lava mapped within these areas consists of sheet, lobate and pillow flows, with aa flows or broken sheet flows mapped along the steeper slopes of the summit. The freshest flows have been identified by Moore and others (1982) as tholeiitic in composition, as compared to older alkalic lava dredged from the Loihi edifice. The broken ends of fresh lava flows frequently observed directly above the talus piles on Loihi indicate that new lava is mechanically disintegrated into talus along the summit slopes shortly after formation, thereby building a submarine volcanic edifice that may be composed of alternating layers of talus and lava flows. Fields of hydrothermal precipitates consisting of blankets and chimneys are all found to be associated with fresh lava flows. No visible hydrothermal vent communities, such as the worm and clam communities observed at the East Pacific Rise or the Juan de Fuca hydrothermal vent sites, were observed in this study. Similarly, no high water temperatures were detected with the acoustic thermometer mounted on the camera sled. Bottom-transponder navigation-controlled dredging of the hydrothermal vent sites produced samples of nontronite; therefore, the hydrothermal blankets and chimneys observed in the photographs are probably constructed of nontronite, iron oxide, and other low-temperature hydrothermal precipitates. Higher temperature polymetallic sulfide deposition may have taken place within the edifice of Loihi during the upward migration of the hydrothermal fluids to the surface. The data described in these studies do not preclude the presence of unmapped high temperature smokers on Loihi. The tectonic, volcanic, and hydrothermal processes observed over the summit of Loihi probably represent submarine geologic processes that may be typical of those active along the summits of emerging hot spot volcanic islands and other major submarine basaltic volcanoes.

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