Lava Inundation Zone Maps for Mauna Loa, Island of Hawai‘i, Hawaii

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Supersedes USGS Miscellaneous Field Studies Map MF–2002–2401

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Introduction

The Island of Hawai‘i is composed of five coalesced basaltic volcanoes (fig. 1). Lava flows from these volcanoes constitute a significant hazard to people and property. This report addresses lava flow hazards from Mauna Loa, the largest shield volcano on the Island of Hawai‘i. Mauna Loa makes up 51 percent of the surface area of the Island of Hawai‘i. From the summit, Hilo lies 36 miles (mi; 58 kilometers [km]) away, the Kona coast 20 mi (33 km) away, and the southernmost point of the island 37 mi (61 km) away.

Hawaiian volcanoes erupt two morphologically distinct types of lava: ‘a‘ā and pāhoehoe. The surfaces of pāhoehoe flows are generally smooth and undulating. Pāhoehoe flows are commonly fed by tubes, which are well-insulated, lava-filled conduits contained within the flows. The surfaces of ‘a‘ā flows are extremely rough, composed of lava fragments. ‘A‘ā flows usually form lava channels rather than lava tubes.

In Hawaii, lava can flow distances of 30 mi (50 km) or more. The flows usually advance slowly enough that people can escape, but anything overwhelmed by a flow will be damaged or destroyed by inundation, crushing, or burning.

Geologic mapping shows that new lava flows resurface more than 40 percent of Mauna Loa every 1,000 years. Since the first written descriptions of its activity in 1832 C.E., Mauna Loa has erupted 33 times. Some eruptions begin with brief periods of seismic unrest, whereas other eruptions start several months to a year following increased seismic activity. Once underway, eruptions can produce lava flows that reach the sea in less than 24 hours, severing roads and utilities in the process. For example, the 1950 flows from Mauna Loa’s Southwest Rift Zone reached the ocean in approximately 3 hours (Finch and Macdonald, 1953).

Mauna Loa will certainly erupt again. When it does, many people, including emergency managers and emergency response personnel, will need to know which areas are threatened with lava inundation. Identifying threatened areas helps delineate the people, property, and facilities at risk from lava. This report provides estimates of the areas that are most likely to be affected by eruptions originating on various parts of the volcano, based on the known source vents and areas affected by past eruptions. We have divided Mauna Loa into potential lava inundation zones and prepared maps of these zones, which are presented on the accompanying map sheets and digital files.

Mauna Loa Overview

Mauna Loa has a summit caldera and two rift zones (fig. 1). The summit is defined as the area above 11,485 feet (ft; 3,500 meters [m]) in elevation. Rift zones—elongate fracture systems on the flanks of the volcano from which lava erupts—extend northeast and southwest from the summit (fig. 1). Most of Mauna Loa’s eruptive fissures and vents are at the summit and along the rift zones. The summit caldera, Moku‘āweoweo, is a depression with steep walls that prevent lava erupted within it from reaching most of the volcano’s flanks. For example, geologic field studies show the summit caldera provides a topographic barrier protecting an area to the southeast from lava flows. The summit caldera also provides a topographic barrier

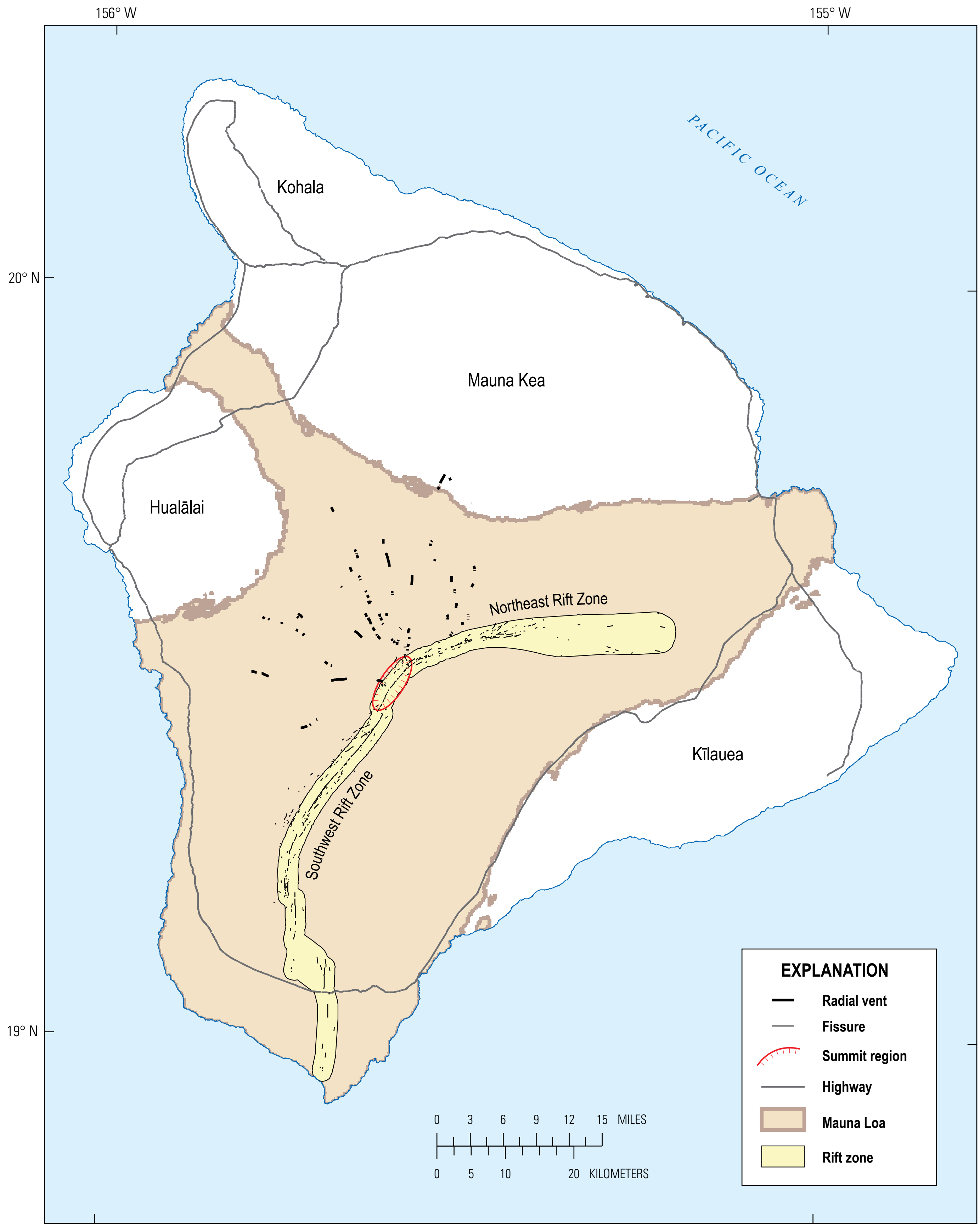

Figure 1. Map of Mauna Loa and other volcanoes of the Island of Hawai‘i. Mauna Loa volcanic features shown, including the rift zones, summit region, fissures, and radial vents.

for an area west of the caldera, but this protection is partly negated by the presence of eruptive fissures—referred to as radial vents—on this flank. Radial vents are absent east of the caldera.

A number of radial vents lie outside of the summit and rift zones. Three of the 33 historical eruptions arose from radial vents. One eruption in 1852 emerged from a north flank fissure, another eruption in 1859 originated from a vent on the northwest flank, and a third eruption in 1877 emerged from a submarine vent on the west flank. Radial vents exist on the west, northwest, and north flanks over a wide range of elevations. Radial vents at lower elevations could initiate lava flows closer to inhabited areas than summit and rift zone vents. The proximity of a radial vent to inhabited areas reduces the emergency response time, leading to a potentially greater risk from radial vent eruptions than from a summit or rift zone eruption.

Geologic mapping of the surface lava flows of Mauna Loa has identified more than 500 flows, ranging in age from 30,000 years old to modern time and originating from the summit area, rift zones, or radial vents. We have delineated approximate pathways of future flows originating in the same, or similar, locations using the distribution of past flows combined with digital elevation models (DEMs) that depict current topography.

These inundation zone maps are part of the ongoing effort to understand the long-term eruptive history and lava flow hazards of Mauna Loa and are sponsored by the U.S. Geological Survey's Volcano Hazards Program.

Purpose

The primary goal of the U.S. Geological Survey's Hawaiian Volcano Observatory (HVO) is to provide scientific information that can be used to reduce risks from volcanic activity. To this end, HVO assesses volcanic hazards to inform and educate emergency responders, public officials, and the public about those hazards. We have identified lava inundation zones—based on detailed geologic mapping and modeling of a fluid's response to the current surface topography—in order to anticipate areas that could be overrun by erupted lava from various source regions.

Accurate estimates of areas that could be affected by lava flows erupted from specific parts of Mauna Loa are critical for emergency managers to quickly warn people living and working in those areas as well as to develop and implement preparedness and response plans. When an eruption starts, the maps presented here will help decision makers to quickly identify communities, infrastructure, and roads between the coast and possible vent locations. The maps will also help emergency managers identify the plausible downslope areas likely to be impacted and decide how to deploy resources to cope with a volcanic event. The maps are intended to make asset allocation more efficient and effective. Although the intent of these maps is to facilitate emergency response activities, the general public can also use the maps to educate themselves for planning and preparedness purposes, should lava flow inundation become imminent.

Methods

Mapping

Extensive fieldwork checked the boundaries of individual lava flows, which were first drawn on vertical aerial photographs taken in 1977, 1978, and 1984, and geologic maps were prepared at a scale of 1:24,000. We created and walked along a grid of transects in places where terrain and vegetation prevented us from walking along the boundaries of past flows. Flow boundaries were then extrapolated from geologic and botanical information encountered along these transects. Flow boundary lines were transferred from the aerial photographs to stable base map material (mylar), referred to as a greenline, with the use of a photogrammetric stereo plotter (Kern model PG-2). Final greenline maps were digitized using a sheet scanner and imported into ArcInfo geographic information system (GIS) software to produce digital geologic maps at a scale of 1:24,000.

Modeling Flow Paths using a Digital Elevation Model

The revised lava inundation zone maps are based on both empirical data (geologic mapping) and hydrologic modeling of the downhill flow path of a lava flow. Lava, like water, flows downhill. Using the hydrologic functions of ArcInfo GIS software and a DEM, we modeled flow paths for potential new lava flows along the steepest descent lines bordered by ridges or topographic boundaries (Hanley and Zimbelman, 1997; Hanley, 1998; Paleo and Trusdell, 2002; Kauahikaua, 2007). The flow path is defined from the point source to the outlet of the catchment following the steepest line of descent.

Our procedure consists of two processes. The first process calculates downhill flow paths using the steepest descent lines from a line input feature. The second process uses a modified DEM with inverted topography (the highest elevation becomes lowest elevation and vice versa) to identify ridgelines, or topographic boundaries, and to separate groups of steepest descent lines or flow paths into lava inundation zones (Paleo and Trusdell, 2002). The two processes use the same basic hydrologic functions of GIS, with the second process using the same input DEM, but multiplying the elevations by -1 to invert the topography prior to analysis.

For this analysis, we used a floating-point DEM with 10 m^2 cells, or rasters, that depict the topography of the island. The vertical uncertainty, as specified by the U.S. Geological Survey, is ±5 m. This DEM was created in 1983, prior to the 1984 eruption of Mauna Loa. Because the 1984 eruption significantly changed the topography of the volcano's summit region and Northeast Rift Zone on both its northeast and southeast flanks, the original DEM needed to be modified to reflect these topographic changes. For this task, we added 2 m to the elevation values of the 1983 DEM for all areas within the boundaries of the 1984 flows. In reality, the thickness of the flows varies significantly and in places is much greater than 2 m, but we determined that a 2-m thickness was a representative and reasonable approximation for most of the flow field. In the flow path calculations, a 2-m-tall feature provides the same obstruction to a steepest descent line as would a feature that is much greater in height.

The mapped distributions of lava flows and DEM modeling were used to construct the 18 inundation zones shown in detail on the 10 map sheets in this report (sheets 1–10). Each inundation zone map shows an area on the flank of Mauna Loa that could potentially be inundated by future eruptions originating from the summit, rift zones, and (or) radial vents. Although any part of an inundation zone could potentially be overwhelmed by a future eruption, it is more likely that only part of a zone would be buried in a single eruption.

Delineation of Inundation Zones

Previous attempts to delineate lava inundation zones on Mauna Loa relied mostly on empirical evidence—geologic mapping of historical and prehistoric lava flows on the volcano. This methodology, described in Trusdell and others (2002), was employed to delineate the inundation zones that we refine in this study. Modeling the flow path of a lava flow requires a reliable DEM and hydrologic modeling routines of GIS.

As an example, we use the subdivisions of Hawaiian Ocean View Estates, Kula Kai, and Hawaiian Ranchos (fig. 2) to show how the lava inundation zones were delineated. The three communities, near the southern extremity of the Southwest Rift Zone, are located in an area at risk from lava flows originating from the same rift segment (fig. 2). The rift segment extends from elevations between 2,840 and 6,480 ft (865 and 1,975 m). The thin black lines in figure 3 represent past lava flows that advanced in the direction of the subdivisions from that segment of the rift zone. We identified flows that originated from the rift segment directly above the target areas and grouped them together to form the first approximation of a lava inundation zone (fig. 4). We then modified the inundation zone border using the ridgelines (topographic boundaries) calculated from the GIS routines using inverted DEM topography. Topographic ridges primarily delineate the zone boundaries, but, in some cases, we use a combination of modeling and empirical data to designate the perimeter extent. For an additional check of the inundation zone extent, we use the geologic mapping to validate the model results.

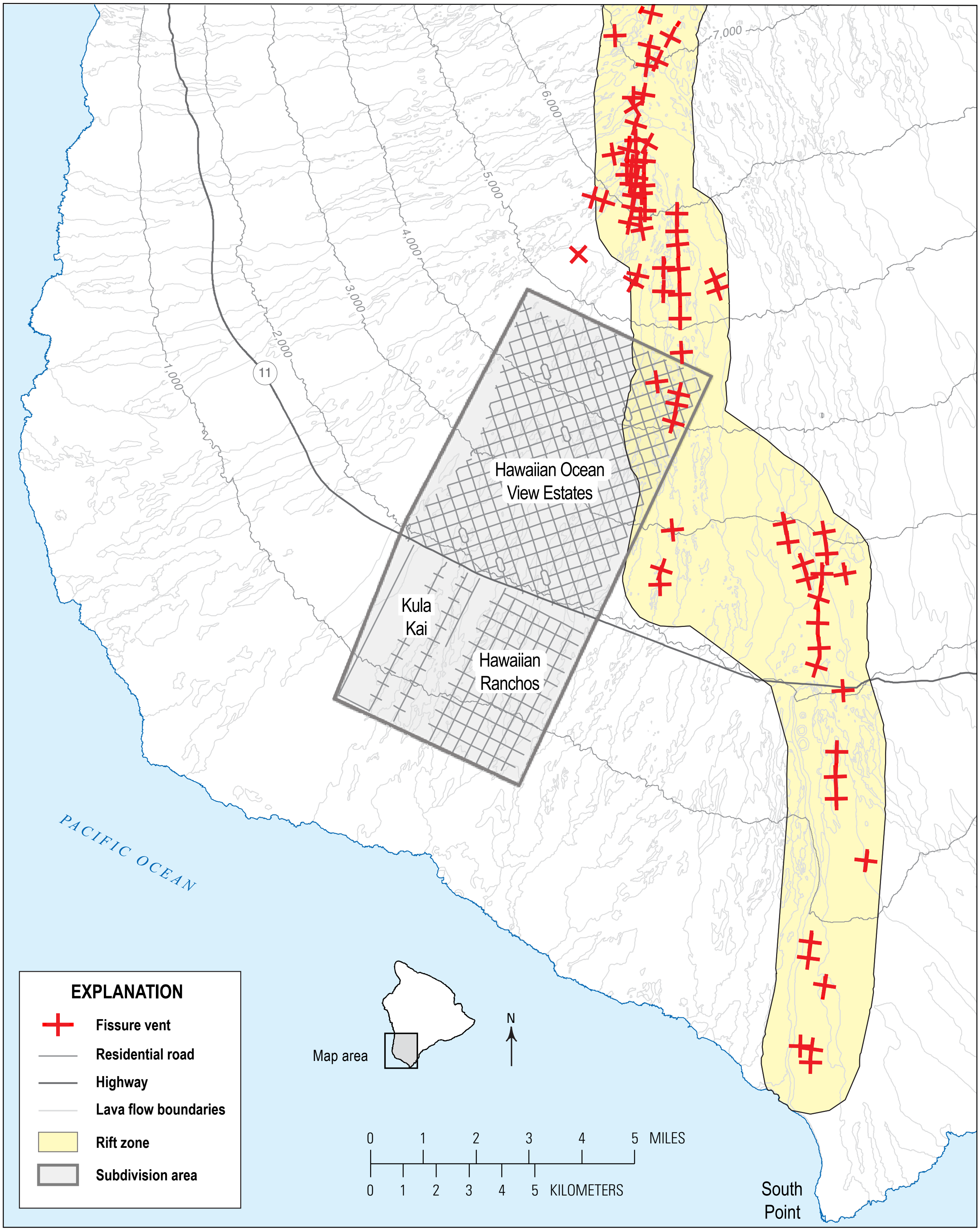

Figure 2. Map showing three communities on the west flank of Mauna Loa's Southwest Rift Zone, including the Hawaiian Ocean View Estates, Kula Kai, and Hawaiian Ranchos subdivisions. Topographic contours modified from U.S. Geological Survey 10-meter digital elevation model. Contour interval, 1,000 feet.

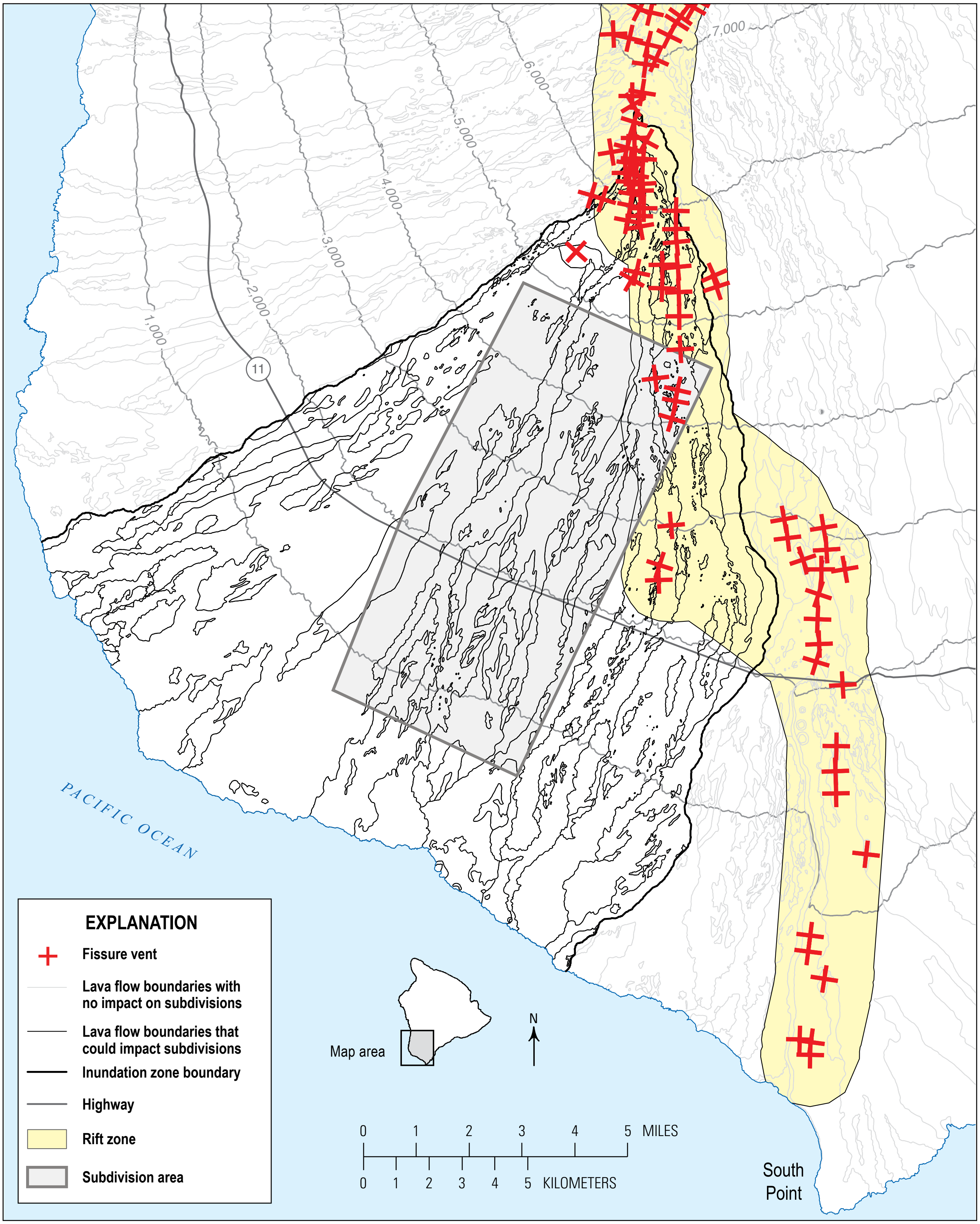

Figure 3. Map showing the rift zone segment that may affect the Hawaiian Ocean View Estates, Kula Kai, and Hawaiian Ranchos subdivisions during a future eruption. Past lava flows that advanced toward the subdivisions are also highlighted. Topographic contours modified from U.S. Geological Survey 10-meter digital elevation model. Contour interval, 1,000 feet.

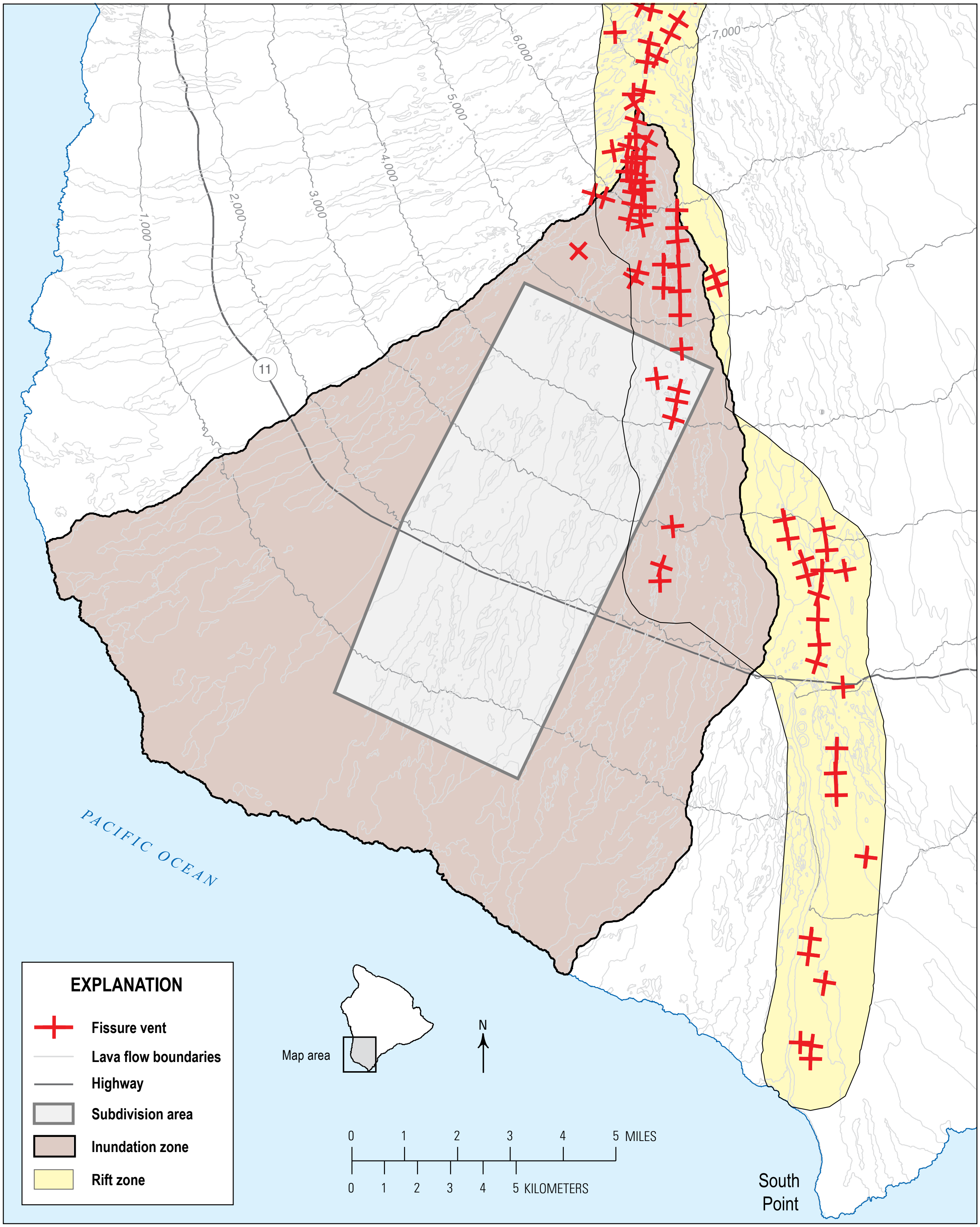

Figure 4. Map showing how lava flows that originate from the rift segment upslope of the Hawaiian Ocean View Estates, Kula Kai, and Hawaiian Ranchos subdivisions group together to form the first approximation of a potential lava inundation zone. This zone incorporates the modeling results and geologic mapping. Topographic contours modified from U.S. Geological Survey 10-meter digital elevation model. Contour interval, 1,000 feet.

Another example illustrates the importance of topography in controlling lava flow distribution. An eruption between elevations of 9,600 and 11,400 ft (2,930 and 3,475 m) on the Northeast Rift Zone of Mauna Loa could produce two dramatically different outcomes, depending on which side of the rift zone axis a future eruptive fissure is located (fig. 5).

- Scenario 1: A fissure erupts on the north side of the rift zone. If a sufficient volume of lava erupts, it may inundate the Kaumana area and downtown Hilo.
- Scenario 2: If a fissure erupts a sufficient volume of lava on the south side of the rift zone axis, it may flow toward Kīlauea and other areas to the southeast. The inundation zone in this area shows that State Route 11, as well as forest and pasturelands, may be covered by lava.

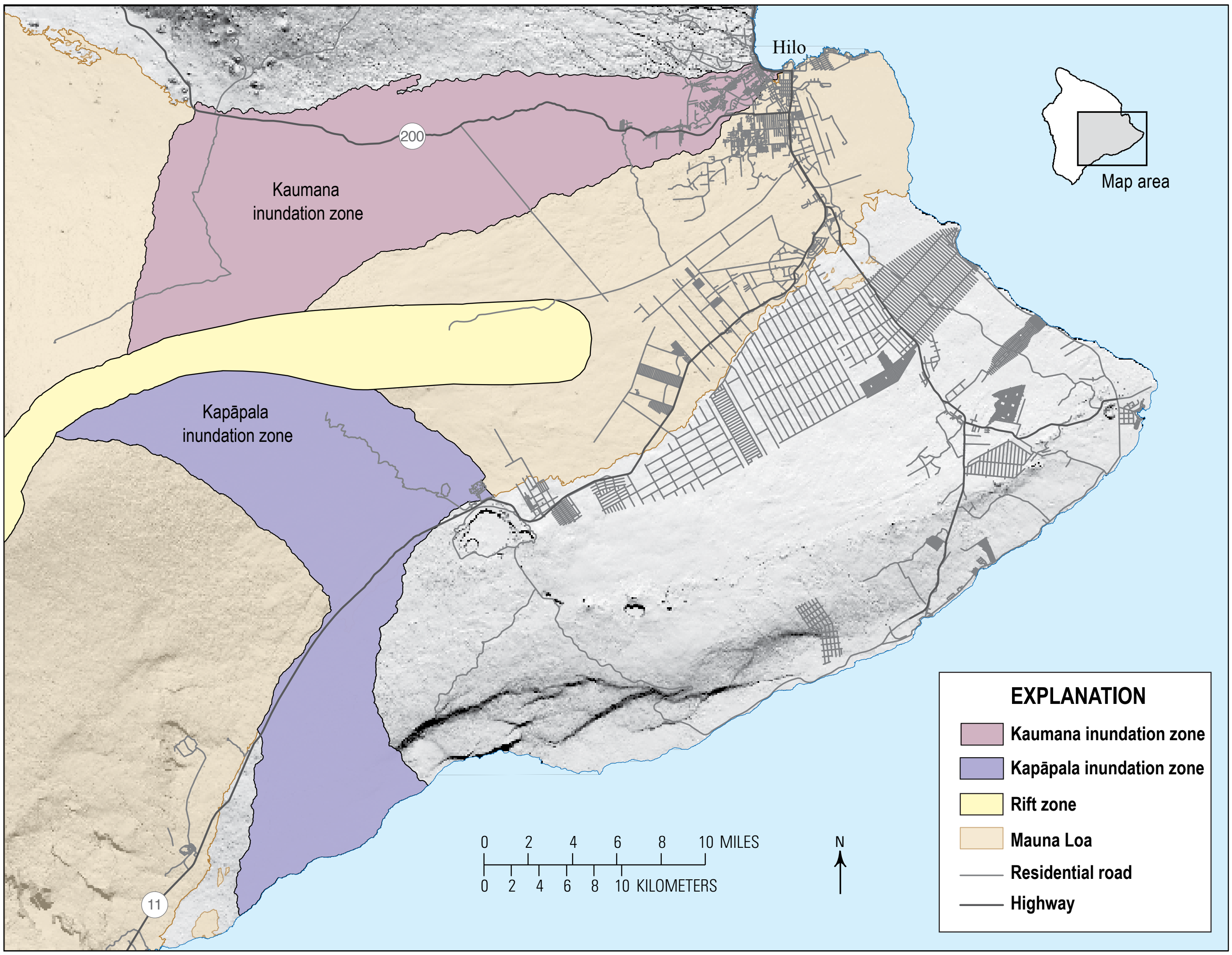

Figure 5. Shaded-relief map showing two inundation zones in eastern Island of Hawai‘i. Lava erupting from a segment of Mauna Loa's Northeast Rift Zone can have varying impacts, depending on which side of the rift zone the eruption occurs. Lava that erupts on the north side may impact Saddle Road (State Route 200), Kaumana, and (or) downtown Hilo. Flows on the southern side, however, may flow toward Kīlauea to eventually reach State Route 11 and other areas to the southeast. Shaded relief from U.S. Geological Survey 10-meter digital elevation model.

Around Mauna Loa, the outer boundaries of several inundation zones were extended 100 m farther than the maximum extent of the mapped lava flows or modeled downhill flow paths (steepest descent lines), whichever was farthest from the source region, to account for uncertainties in topography and flow dynamics. The zones that received this additional buffer are identified in figure 6. The full breadth of the resulting inundation zones produced in this study extends from the outer boundaries of the inundation zones—coast or otherwise—to the Mauna Loa rift zone buffer (fig. 6).

Mauna Loa Inundation Zones

Nine maps depicting 18 inundation zones were created for Mauna Loa (their outlines are shown in fig. 7 and sheet 1), following the procedures described above. We recognize that many more homes, small communities, and facilities occupy the slopes of Mauna Loa than are explicitly identified on the inundation zone maps. Homes, communities, and facilities that are not specifically identified on these maps should expect lava flow hazards at least at the same level as the communities and facilities that are shown (Wright and others, 1992).

The inundation zones identified on the nine maps are Kaumana, Waiākea, and Volcano-Mountain View (sheet 2); Kapāpala and Wood Valley (sheet 3); Pāhala, Punaluʻu, and Wood Valley (sheet 4); Nāʻālehu (sheet 5); Kalae (sheet 6); Hawaiian Ocean View Estates, Kapuʻa, and Miloliʻi (sheet 7); Hoʻokena, Kaʻohe, and Kaʻapuna (sheet 8); Hōnaunau and Kealakekua (sheet 9); and Puako (sheet 10). The names given are descriptive and are meant to represent the larger geographic areas of potential lava inundation. Map scales vary from 1:45,000 to 1:85,000. The lava inundation maps are available online at https://doi.org/10.3133/sim3387.

User Guidelines

These maps are intended as a general guide to assist emergency managers during an eruption, to plan emergency response activities, and to identify communities and infrastructure at risk. Inundation zones do not reflect what will be covered by an eruption from a given segment of the rift zone but, instead, only the total area that could potentially be impacted. Several factors may affect the interpretation of an impending lava flow inundation.

1. Before specific, actual inundation zones can be identified during an eruption, it is critical to identify the specific locations where lava begins to flow down the volcano's flanks. Radial fissures are likely to send lava downslope immediately. However, the paths of lava flows from rift zone eruptions may not be obvious because of the great variation in topography within rift zones. For example, high topographical features, such as cones and spatter ramparts, and low topographical features, including ground cracks, old eruptive fissures, lava channels, and down-faulted areas (called grabens), may affect the flow of lava. These features can cause flows to exit rift zones in unexpected places and directions. Therefore, lava must leave the rift zone buffer (yellow area on maps) before the affected inundation zone can be identified. This information will most likely come from scientists at the U.S. Geological Survey's Hawaiian Volcano Observatory.
2. Inundation zones show the total area that may be affected by specific source vents in future eruptions. In a single eruption, it is likely that only part of a zone will be inundated. The final area covered by lava is a function of eruption duration, slope, magma supply, and topography.

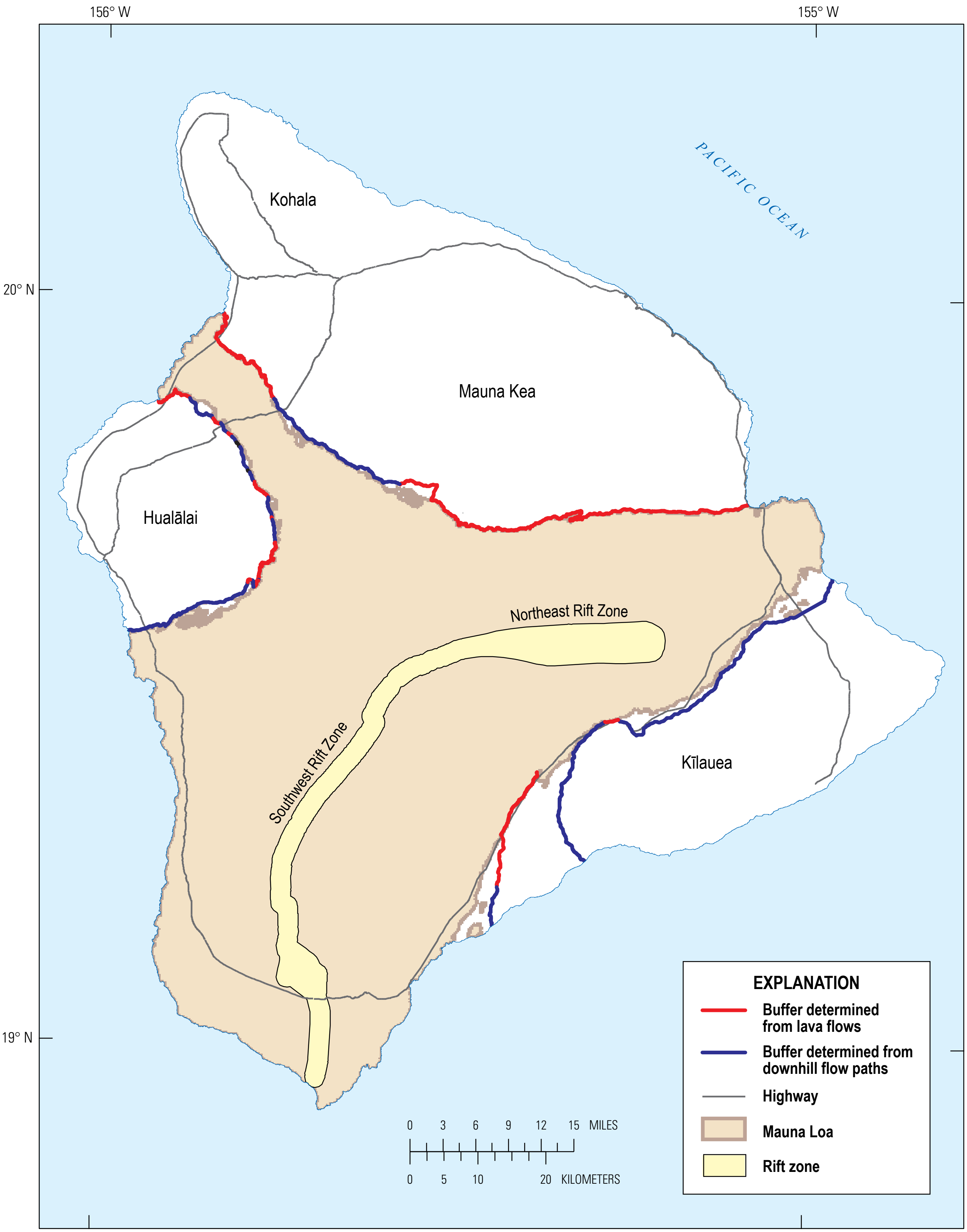

Figure 6. Map of buffered inundation zone boundaries. Red lines represent a 100-meter-wide buffer determined from Mauna Loa lava flows and blue lines represent a 100-meter-wide buffer determined from modeled downhill flow paths (steepest descent lines). Most boundaries are known to within ±120 meters; refer to metadata for more information on spatial accuracy and boundary definitions.

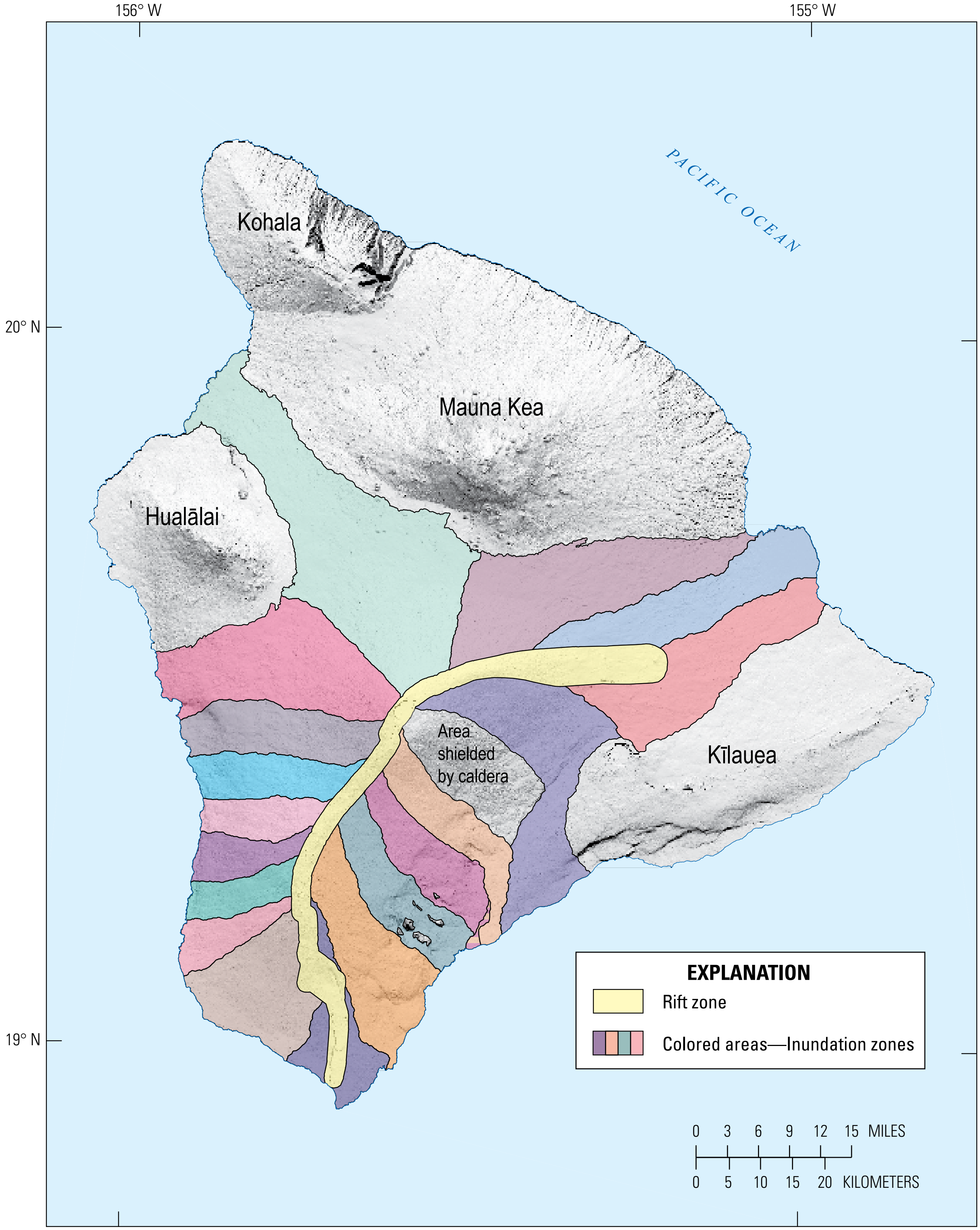

Figure 7. Revised Mauna Loa lava inundation zones determined in this study. See sheet 1 for location of specific lava inundation zones. Shaded relief from U.S. Geological Survey 10-meter digital elevation model.

3. The boundaries between inundation zones are approximate. Our estimation of the positional accuracy of each lava inundation zone boundary is defined in the metadata for the inundation zone boundary GIS file (contacts feature data). The precise influence of local topographic features on the course of a new lava flow is necessarily uncertain. The uncertainty in flow direction increases as the slope angle decreases and is especially high in areas where the slope is less than about 5 percent. In low slope settings, lava flows have a tendency to spread laterally and decrease flow-front velocities, which can result in the creation of breakouts or secondary flow lobes. Forests, shown in detail on map sheets, also contribute to this uncertainty in many areas. In other situations, topographic barriers may be overtopped by ponding and (or) inflation of flow lobes. Both ʻaʻā and pāhoehoe flows follow the topography, but pāhoehoe flows are more sensitive to small topographic features. In addition, the topography of newly emplaced lava flows will influence the course of subsequent flows. Furthermore, lava may flow out of one inundation zone into an adjacent inundation zone, especially if a lava flow is spreading near a boundary.

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