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Emplacement of the 1907 Mauna Loa basalt flow as derived from precision topography and satellite imaging

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ABSTRACT

An eruption in January of 1907, from the southwest rift zone of Mauna Loa, produced a substantial lava flow field. Satellite images and Differential Global Positioning System (DGPS) survey data, along with observations and photographs from the field, are combined to provide a new perspective on the 1907 eruption. Boundaries of the flow field from the satellite data, combined with field measurements of flow thickness, indicate an area of 25.1 km^2 and a volume of 86.6 million m^3. The eastern lobe of the flow field covers an area of 13.1 km^2, with a volume of 55.0 million m^3, and was emplaced with an average effusion rate of 119 m^3/s (at least, for the upper portion of the lobe). Ten DGPS topographic profiles across the eastern lobe aid in distinguishing the characteristics of, and transitions between, the zones identified during the emplacement of the 1984 Mauna Loa flow. Several subdivisions have been built directly on top of or adjacent to the 1907 lava flow. The strong likelihood of future eruptions from the Mauna Loa southwest rift zone makes these housing developments of particular importance for assessments of potential volcanic hazards.

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1. Introduction

Mauna Loa is recognized as the world's largest volcano (e.g., Macdonald and Abbott, 1970, p. 292; Lipman, 1980; Lockwood and Lipman, 1987; Lipman, 1995; Trusdell, 1995). A recent reassessment of the volume of this volcano, including isostatically depressed igneous materials beneath the present mountain, leads to a value of at least 80,000 km^3 (Lipman, 1995). Lavas from Mauna Loa cover 5125 km^2 of the Big Island of Hawaii, with lavas of known historical age (1843 and later) covering 13% of Mauna Loa's surface (Lockwood and Lipman, 1987). Recent mapping has revealed that lava flows have covered the surface area of Mauna Loa at a rate of 30–40% every 1000 years (Trusdell, 1995), with potentially high recurrence rates of burial beneath a new flow near the two major rift zones of the volcano (Kauahikaua et al., 1995). This report focuses on the 1907 eruption from the southwest rift zone, making use of new topographic transects and satellite imaging to provide new insights into the emplacement of this historic flow. Lessons learned regarding the emplacement of this relatively recent major eruption of Mauna Loa have important implications for the people already living on this remarkably active volcano, particularly where housing is situated near or downslope from a rift zone.

2. Background

2.1. Mauna Loa volcano

The subaerial portion of Mauna Loa volcano is the exposed top of an enormous pile of volcanic rock that rises ~9.5 km above the floor of the Pacific Ocean (Macdonald, 1972, p. 275), the result of countless superposed lava flows from eruptions that spanned ~600,000 yr, the first half of which the growing volcano was likely below the surface of the ocean (Moore and Clague, 1992). Enormous landslide deposits have been identified through bathymetry around all of the Hawaiian Islands, including several large slides originating from the southern end of the Big Island (Moore et al., 1989; Eakins et al., 2003). The enlongate shape of the volcano (Mauna Loa means 'long mountain' in Hawaiian) is the result of two principle rift zones extending downslope from Mokuaweoweo caldera that have concentrated the growth of the volcanic construct along the axes represented by the southwest rift zone (SWRZ) and the northeast rift zone (NERZ) (Macdonald and Abbott, 1970, p. 303). The SWRZ makes a bend at its southern end to form an en-echelon series of N–S vents, three of which were the sources for lava flows erupted in 1868, 1887, and 1907 (Wolfe and Morris, 1996). The 1907 lava flow is the westernmost of the three historic eruptions on the southernmost subaerial portion of Mauna Loa (Fig. 1) (Barnard, 1995). The primary source for the 1907 flow is a fissure located between 1820 and 2000 m elevation, with small secondary vents east of the main flow at elevations of ~740, ~780 and ~920 m (Wolfe and Morris, 1996). The 1907 lava, outlined in white in Fig. 1, covers 25 km^2, of which 13 km^2 is included within the easternmost branch of the flow field.

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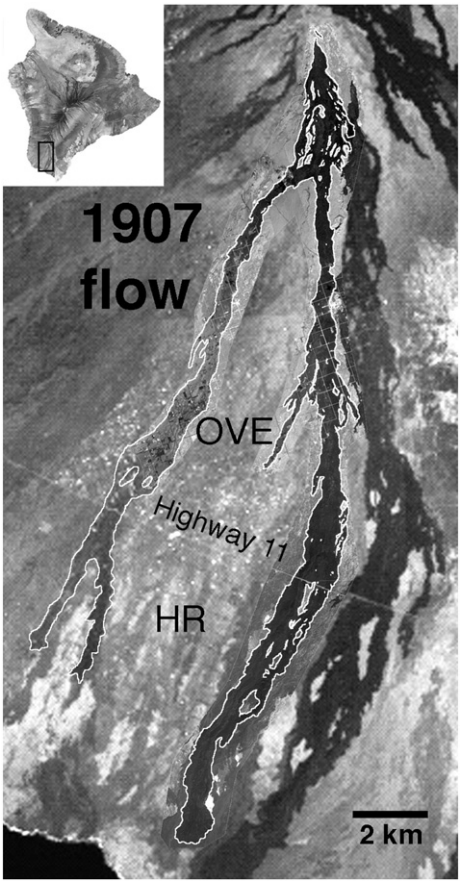

Fig. 1. Regional view of the 1907 flow, surrounded by a white line. OVE stands for Ocean View Estates, HR stands for Hawaiian Ranchos; both are subdivisions with extensive road grids. Landsat image with superposed Ikonos mosaic (data from Hawaii Synergy, 2002).

The general characteristics of all historical eruptions of Mauna Loa from 1843 to 1984 are given in Table 18.1 of Lockwood and Lipman (1987), which indicates a total of 806 km^2 was covered by 4.12 km^3 of lava from 33 separate events. A plot of the cumulative number of historical eruptions as a function of time shows a pronounced increase in eruption frequency between 1870 and 1880 and a definite decrease in eruption frequency since 1950, as compared to what appears to be the more typical eruption frequency for other times (Fig. 1 of Decker et al., 1995). Cumulative rates of coverage by lava flows were derived from mapped relationships where the flows are well dated, a technique that has been applied to the abundant volcanism along the SWRZ of Mauna Loa (Lipman, 1980). Eruptions since 1907 along the SWRZ occurred in 1916, 1919, 1926, all from vents at elevations above 2000 m, including several large flows from the eruption in 1950 (Lockwood and Lipman, 1987; Wolfe and Morris, 1996). The Ka'apuna flow from the 1950 eruption of the SWRZ originated at 2400 m elevation and reached the ocean (on the Kona side of the island) in just over 2 h from the beginning of the eruption (Finch and Macdonald, 1953).

'Surges' must also be considered in relation to the final shape and morphology of Hawaiian lava flows. Surges were commonly observed in the early Kilauea eruptions, as first described by Neal and Decker (1983), where an upflow obstruction can pond lava that is subsequently released in a large pulse. For example, a surge was observed from within the Royal Gardens subdivision on March 3, 1983; a 2-m-high flow front was moving downslope at <1 m/min, but then thickened slowly to 6 m and surged ahead ~200 m in only 30 min, during which time it thinned back down to 2-m thickness (Wolfe et al., 1988). Surges are now recognized as important contributors to overflows that build up levees, and may be a prime factor in breaches of channels that lead to new flow lobes.

Wright et al. (1992) produced a hazard zones map of the island of Hawaii; hazard zone 1 (confined to summit calderas and rift zones) has >25% of the surface covered by lava in the past 200 years, 15 to 25% of the surface area of hazard zone 2 and 5% of hazard zone 3 have been covered by lava during the same time period, with hazard zones 4 through 9 reflecting progressively decreasing frequency of eruptions or areas that are shielded from lava flows by topography. Not surprisingly, the entire 1907 flow field falls within their hazard zones 1 and 2.

2.2. 1907 eruption

Barnard (2002) provides an extensive collection of newspaper and other published accounts of historic eruptions of Mauna Loa, and the following is summarized from his compilation of several eye-witness accounts. The eruption started during the late evening of January 9, 1907, with a strong red glow from the summit area of Mauna Loa clearly visible from Hilo throughout the night, but which rapidly subsided by about 5 am. On January 10 the eruption shifted to the lower SWRZ, where lava reached and crossed the 'Government Road' within two days, on the Kona side of the lava flow of 1887. A second flow lobe later cut the government road a few miles to the west of the first lobe. Visitors who eventually reached the flow itself reported thicknesses of 15 to 30 ft (4.6 to 9.1 m) where both flows crossed the government road, and at the (distal) end it attained a thickness of over 50 ft (15.2 m). The 1907 SWRZ eruption ended after 15 days.

Tabulated data for all historical eruptions of Mauna Loa list the area covered by 1907 lava as 3 km^2 inside the Mokuaweoweo (summit) caldera and 25 km^2 outside the caldera, with estimated lava volumes of 5 and 116 million m^3 inside and outside the caldera, respectively (Table 18.1 of Lockwood and Lipman, 1987). Lipman (1980) gives a volume for the 1907 SWRZ lava of 110 million m^3 as a refinement of the 85 million m^3 volume estimated by Stearn and Macdonald (1946). Decker et al. (1995) use 75 million m^3 as the volume of lava erupted during the 1907 event, without an explanation for the discrepancy with the Lockwood and Lipman (1987) estimated volume. Below we present a new estimate of both the area and volume of the 1907 flow based on mapping of satellite imaging data and numerous field measurements of the margin thickness.

2.3. Development near the 1907 flow

The area around the 1907 flows is the site of the largest subdivision project within the state of Hawaii. The Hawaiian Ocean View Estates subdivision was officially established in September of 1961 (Trusdell, 1995), but the project development started in the late 1950s by the Crawford Oil Company, consisting of Walter and Lillian Crawford and their two sons (Ocean View Chamber of Commerce, 2006). The area is now known collectively as "Ocean View", which encompasses the original Hawaiian Ocean View Estates (north of state highway 11) along with the subsequent developments of Hawaiian Ocean View Ranchos, Kahuku Country Gardens, Kula Kai View Estates, Kona Garden Estates, Keone's Ranchos, and Kona View Estates, cumulatively consisting of ~1500 homes at present (Ocean View Chamber of Commerce, 2006). Here we use the name Ocean View Estates (OVE) to refer to all of the subdivision located north of state highway 11, and Hawaiian Ranchos (HR) for a subsequent development south of the highway and west of the eastern lobe of the 1907 flow (Fig. 1).

An extensive array of paved roads covers OVE in a 1/4-mile (400 m) grid set at a diagonal relative to north, but which allows cars to climb the Mauna Loa slope at an angle that is typically oblique to steepest local slope. Nine ovals are also scattered throughout the road pattern. Lillian Crawford, one of the original developers, named all of the 156 miles (250 km) of roads built within the subdivision (Ocean View