"FILL AND SPILL" LAVA EMPLACEMENT ASSOCIATED WITH THE DECEMBER 1974 FLOW ON KĪLAUEA VOLCANO, HAWAI'I, USA.

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Introduction: Lava flows are common on terrestrial planets and moons throughout the Solar System [1] and can provide information about thermal history and interior of these bodies. However, to correctly infer eruption parameters and source characteristics from observations of flow dimensions and their morphologies, it is critical to understand how lava transport processes can affect local discharge rates and mask the signature of magma effusion rates at the vent.

This study focuses on the December 1974 flow, located in the Southwest Rift Zone of Kīlauea Volcano in Hawai'i (Fig. 1) [2–6]. The study area was chosen because it exhibits a wide range of lava facies, including lobate pāhoehoe margins, channelized 'a'ā flows, and transitional lava facies, including: platy pāhoehoe, slabby pāhoehoe, rubbly pāhoehoe, spiny lava, and smooth overbank flows. These transitional lava facies are important because they provide evidence of local surges in discharge rate that are related to sudden releases of lava stored within a lava transport system. Analogous "fill and spill" emplacement processes operating on other planets, such as Mars, may account for the exceptionally high discharge rates calculated for some eruptions [7,8].

Geological Context: On December 31, 1974, a series of en echelon fissures opened southwest of Kīlauea Caldera. During the next 6.5 hours lava was emplaced as a rapidly emplaced sheet-like flow, with an average effusion rate of 270 m^3/s [2–6]. The December 1974 flow has been used as a location for radar roughness studies [9] due to the exposure of abrupt changes in surface texture from smooth pāhoehoe to rubbly and slabby lavas [5]. When viewed in visible remote sensing imagery, this flow field displays dark- and light-toned areas that reveal sinuous patterns, streamlined islands, and rafted lava slabs and plates. However, Soule et al. [5] have demonstrated that these sinuous patterns are related to surface texture alone, and not the development of traditional, topographic levee-bound channels. Islands between sinuous pathways of rough terrain in the proximal section of the flow field formed around high-standing outcrops (kīpuka) of older lava flows [10]. The flow thickness was estimated to be several meters at most, and generally on the order of 1-m-thick in the proximal regions, before transitioning to a channeled 'a'ā flow ~2 km from the vent [5].

Methodology: Fieldwork on the December 1974 flow was completed during the Summer of 2014 focusing on section of the flow that abuts against a prominent fault scarp, belonging to the Koae Fault System. Field measurements included detailed observations of flow characteristics, including facies descriptions and maps to determine the emplacement history of the flow. These qualitative descriptions were also augmented using airborne LiDAR data, ground-based Tripod-LiDAR data, Differential Global Positioning System (DGPS) measurements, and Multi-View Stereo Photogrammetry (MVSP) from ground-based and kite-aerial photography platforms [11].

Results: The main study area, encompassing a 0.20 km^2 region (Fig. 1) shows evidence of basin infilling with a prominent "bathtub ring" forming a lava highstand that is elevated 0.6–1.7 m above the current surface of the lava pond. The lava pond itself has one influx channel (entering from the northeast) and two spillways (exiting to the southwest). The total area of pond is 0.11 km^2, suggesting that $6.6–18.7 \times 10^4$ m^3 of lava exited the pond during a drainage event. The pond includes pāhoehoe lobes along its margins, but the interior features an ensemble of meter- to tens of meter-wide plates with a jigsaw fit that are separated by zones of spiny lava. The plates have a smooth to folded pāhoehoe-like surface that commonly exhibit polygonal ("turtle-back") swales resembling those on the surface of lava lakes such as Kīlauea Iki. Lava adhering to the on the fault scarp exhibits tool marks showing that as the lava level continuously fell from its highstand elevation, the flow direction was down and to the southwest. The pond also shows to parallel shear zones along its southern and northern margins. These shear zones include kinematic indicators, such as lava coils, which indicate that the central portion of the pond was transported southwest toward the southern egress point. Along the southwestern margin of the pond, the high-stand of the December 1974 flow onlaps onto older, tan-colored tumuli, which appears to have formed a "leaky barrier" that confined the younger flow. Along southwestern margin of the December 1974 flow, the platy surface of the pond has been disrupted into a crescent-shaped ridge composed of a jumbled assortment of pāhoehoe-like upper crustal slabs. The southwestern spillways transition into rubbly pāhoehoe and 'a'ā where the lava flowed from the upper perched pond ("A" in Fig. 1) to a lower pond ("B" in Fig. 1). Along the margins of these channelized spillways the flow exhibits streamlined textures within thin (i.e., cm-thick) pāhoehoe-like sheets.

Interpretation: We infer that lava erupted from the source vent fissures of the December 1974 flow travelled south-southwest until it encountered a steep southern margin of the Southwest Rift Zone's graben. The lava then began to fill a topographic depression formed between older flow units and the fault scarp. As the lava level rose within the basin, pāhoehoe-like margins began to embay the surrounding lava, gradually inflating to build perched lava pond that was elevated nearly above the surrounding low points in the pre-eruption topography. Within a few hours (based on the cooling-limited thickness of the disrupted pāhoehoe slabs [12]), the perched lava pond suddenly breached its confinement to the southwest and began to catastrophically drain. This caused the stable crust of the pond to separated into a series of large plates, with spiny lava upwelling between the newly formed cracks. The surge of lava toward the southwest also caused the surface of the pond fracture and pile up against the surrounding tumuli to form a pressure ridge composed of slabby pāhoehoe. The sudden increase in the local discharge rate during the drainage event also produced a new lava high-stand down flow, along the margins of the spillway, with overbank lava producing thin streamlined flow units that bound the spillway channels. Within the channels, elevated discharge rates caused shear-induced disruption of the flow surface, breaking apart pāhoehoe plates into rubbly pāhoehoe and forming ʻaʻā clinker. This lead to the formation of a second lava pond downflow, which exhibits a much rougher surface ("B" in Fig. 1). The process of basin infilling and drainage, which we term "fill and spill" emplacement, was repeated several times along the length of the December 1974 flow, producing a lava flow field composed of a series of basins interconnected by sinuous spillway channels.

Conclusions: The "fill and spill" emplacement process documented with the December 1974 produced a range of transitional lava flow types that differ from standard pāhoehoe facies and ʻaʻā end-members. This eruption also highlights the importance of local effects on controlling discharge rates, which can be largely decoupled from changes in effusion rate at the vent. Analogous "fill and spill" process could affect lava flow emplacement on other planetary surfaces, particularly during flood lava eruptions, which can inundate large regions and form voluminous perched ponds. Sudden release of lava stored within such temporary reservoirs could then produce local discharge rates that are orders of magnitude larger than the magma effusion rates at the vent. This suggests that caution should be exercised with inferred eruption parameters from lava high-stand conditions.

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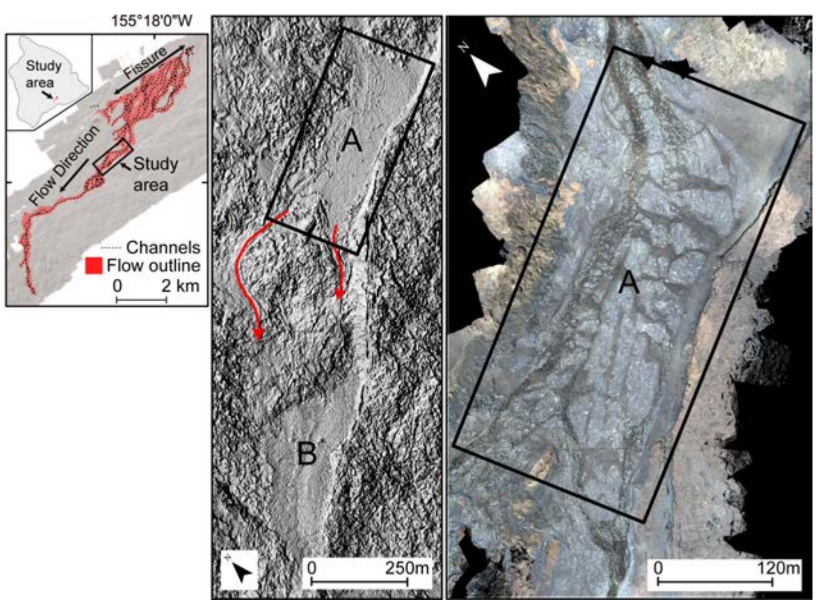

Figure 1. Left: Context of the study area within the December 1974 flow in Hawaiʻi, showing the extent of the available airborne LiDAR data (after [6]). Center: LiDAR shaded relief map of the study area showing the location of the upper perched pond ("A") and the lower pond ("B"). Arrows indicate the locations of the two spillways and the black box shows the location of the visible image mosaic shown in the right panel. Right: High-resolution (1.67 cm/pixel) orthophoto mosaic of the upper lava pond obtained using kite-aerial photography [11].